GRANULATED SLAG PILE
DRAFT STAGE 1
REMEDIAL INVESTIGATION REPORT

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for
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I. INTRODUCTION

This Remedial Investigation (RI) Report for the granulated slag pile at the Anaconda Smelter site has been completed in accordance with the Anaconda Smelter Remedial Investigation/Feasibility Study work plan (CH$_2$M HILL, 1984). This report summarizes the findings of the field investigations and literature review, and the conclusions regarding potential public health endangerment.

TASK BACKGROUND

The evaluation of the granulated slag pile is one of four Focused Investigations that address potentially hazardous materials at the smelter site. Each focused investigation proceeds independently through the Remedial Investigation (RI), Endangerment Assessment (EA), and if necessary, the Feasibility Study (FS) process. This focused investigation begins in Stage I of the Remedial Investigations. Should important data gaps exist after execution of the Stage I studies, the investigation would then move into Stage II in order to fill the data gaps.

SLAG INVESTIGATION OBJECTIVES

The primary purposes of the Remedial Investigation activities are to characterize contamination and physical/chemical environmental parameters in sufficient detail to facilitate the Stage I Endangerment Assessment. In order to meet the EA analytical requirements, certain information regarding the granulated slag pile must be obtained. The objectives of the Focused Investigation are:

- Describe the physical characteristics of slag and determine the ability of wind and surface runoff to move slag from the pile.

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- Provide measurements of area, volume, and mass of the slag pile.

- Describe the chemical composition of slag.

- Evaluate whether trace elements are readily leached from slag, and identify which elements may be most mobile.

- Determine whether data collected in this task provide sufficient information to answer questions about levels of contamination and contaminant movement from the slag pile.

In order to meet these objectives, the Work Plan proposed four major subtasks: Literature and Data Review, Field Study, Laboratory Analyses, and Data Reduction and Analysis. The Literature and Data Review includes the review of meteorological records and an evaluation of the chemical characteristics of slag, the potential for transport of pollutants away from the slag pile, and the migration of heavy metals in surface and groundwaters.

The elements of the Field Work have been defined in detail during Task 3 of the RI/FS: Field Operations Planning. A Field Operation Plan (Tetra Tech 1984) was specifically developed for the granulated slag pile. The results of the field work were presented in a data report (Tetra Tech 1985) which is included as Appendix A to this RI report. The data report has been updated to include quality assurance/quality control and sulfur data unavailable at the time the draft data report was submitted.

This report is organized according to the EPA draft guidance report for remedial investigations (JRB Associates 1984). Some deviations from the suggested report outline have been made to specifically address the granulated slag pile and to make the report easily readable. Sections describing biota investigations, air quality, and bench and pilot tests have been excluded because they are not germane and were not included in the work plan (CH$_2$M HILL 1984).

NATURE AND EXTENT OF THE PROBLEM

Environmental and public health concerns about the granulated slag pile pertain to the presence of metals in the slag. Certain metals can be toxic to humans and other organisms depending on the chemical form and concentration present.

Potential pathways of release of metals from the slag pile resulting in human exposure include:

- Leaching and dissolution of metals resulting in contamination of groundwater

- Runoff of metal contaminated water to surface waters

- Generation of airborne particulates.

These three pathways and the potential pollutant migration via each pathway will be examined in this report.

II. SITE FEATURES INVESTIGATION

SITE BACKGROUND INFORMATION

The granulated slag pile is located within the Anaconda Reduction Works, immediately southeast of the Community of Anaconda (Figure 1). The facility is situated at the western edge of Deer Lodge Valley, a broad intermountain valley at an elevation of approximately 5,400 ft. The slag pile is located adjacent to Highway 10A, directly north of the smelter stack.

From 1884 to 1980, copper ore from Butte mines was processed at facilities at Anaconda. In 1902, facilities were developed at the present smelter site on the south side of Deer Lodge valley about 1/2 mile east of Anaconda. Ore was mechanically concentrated, roasted, and smelted in reverberatory furnaces to produce copper matte and slag (as a waste product). The slag was continuously wasted into a stream of water which cooled and granulated it. The slag slurry was transported to the waste pile through a system of flumes.

The areal extent of the slag waste area was calculated to be 130 acres. The estimated volume and mass of the waste slag material on site was calculated to be 16 million yd^3 and 26.5 million tons, respectively.

All field and background investigation findings pertinent to this Remedial Investigation have been summarized in the data report (Tetra Tech 1985) included as Appendix A of this report.

DEMOGRAPHY

Population centers in the vicinity of the Anaconda Smelter site include the communities of Anaconda, Mill Creek, Opportunity, Warm Springs, Warm Springs State Hospital, and Deer Lodge. There are also nearby rural residents. Of the 12,518 residents of Deer Lodge County in 1980, approximately 10,500
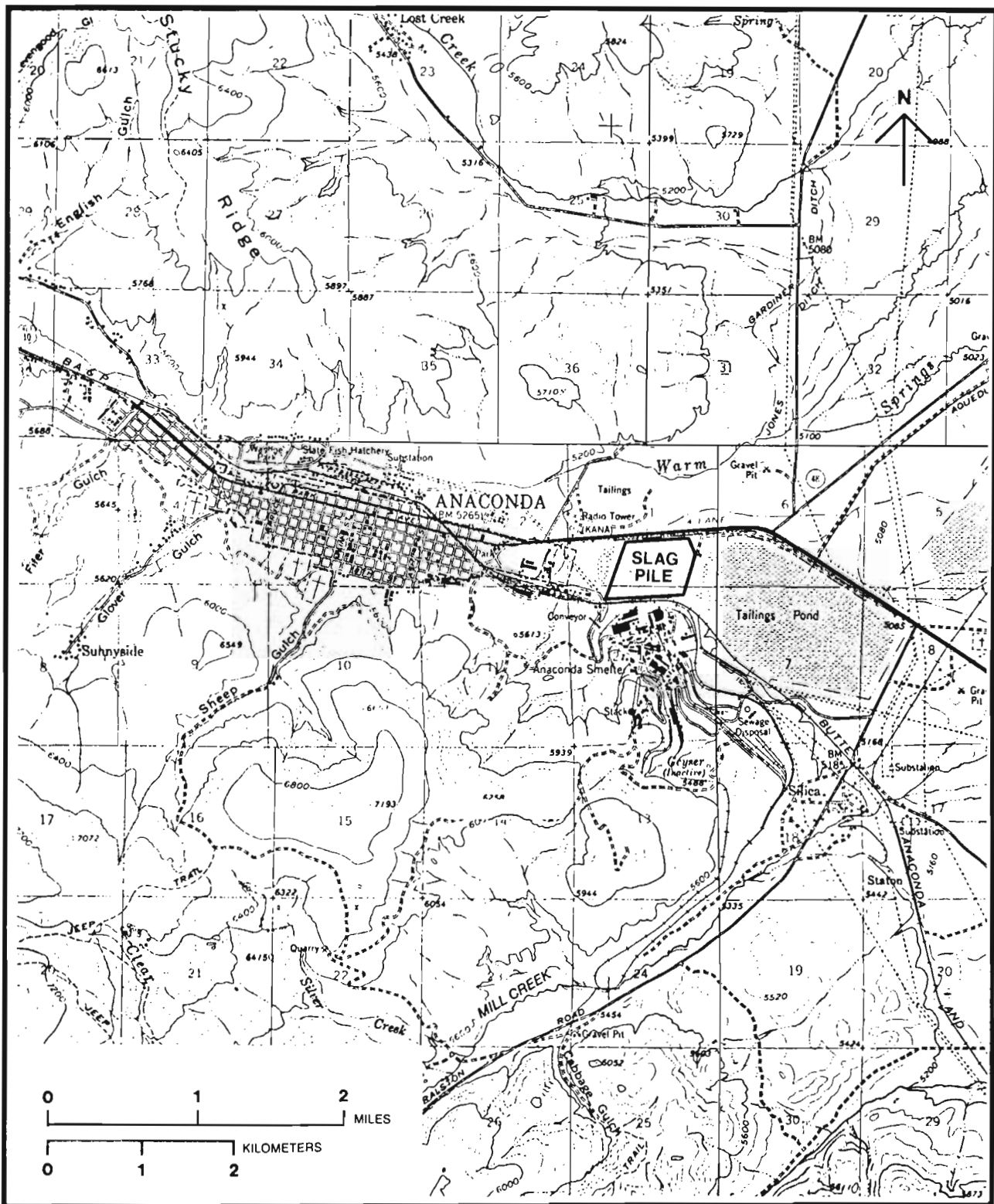
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Figure 1.   Anaconda Smelter: location of the granulated slag pile.

(84 percent) resided within the city limits of Anaconda, 1.5 miles west of Smelter Hill, less than 100 resided in Mill Creek (Silica), and the remainder resided within Warm Springs and rural areas. Deed Lodge, Montana, is located in Powell County, approximately 30 miles north of the smelter and has approximately 4,000 residents (CH$_2$M HILL 1984).

LAND USE

All land immediately surrounding the slag pile is owned by the Anaconda Minerals Company. Land use in the vicinity of the slag pile includes industrial operations of the nearby smelter (now being demolished) and a meteorological station (now closed) at the summit of Weather Hill. Remaining lands adjacent to the site are semi-arid foothills forming part of the Warm Springs Creek watershed. There are no other nonindustrial land uses.

NATURAL RESOURCES

Vegetation in the vicinity of the slag pile includes ryegrasses and small shrubs. The surrounding foothills provide cover and habitat for mammals, birds, reptiles, and insects. Many of the larger mammals (e.g., deer, bear) would probably never occupy the slag pile site because of the lack of water. These animals prefer the more densely forested areas of higher elevations or the more watered areas of the valley streams. The site investigation revealed no evidence of vegetation on the slag pile or wildlife in the vicinity.

CLIMATE

Climate in the Anaconda area is a semi-arid continental type with cold winters, cold summers, and low precipitation. Weather records collected by the National Oceanographic and Atmospheric Administration (NOAA) and the Anaconda Minerals Company are available for a site near the east entrance to the smelter. These data include temperature and precipitation data for the period 1906 through 1978 and evaporation data for the period 1974 through 1978. Average values for this period of record are shown in Figure 2.

AVERAGE MONTHLY PRECIPITATION[1] AND EVAPORATION[2]

AVERAGE MONTHLY TEMPERATURE[1]
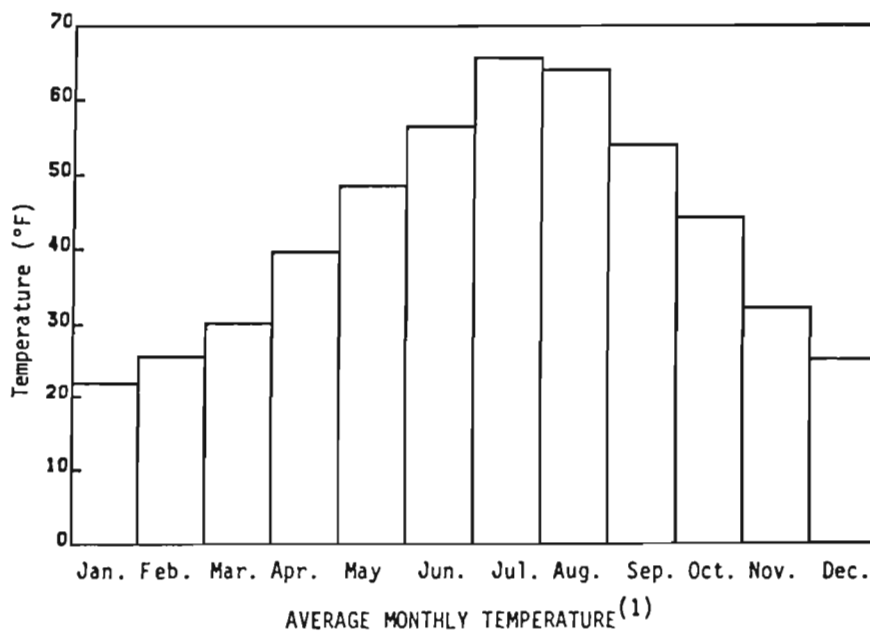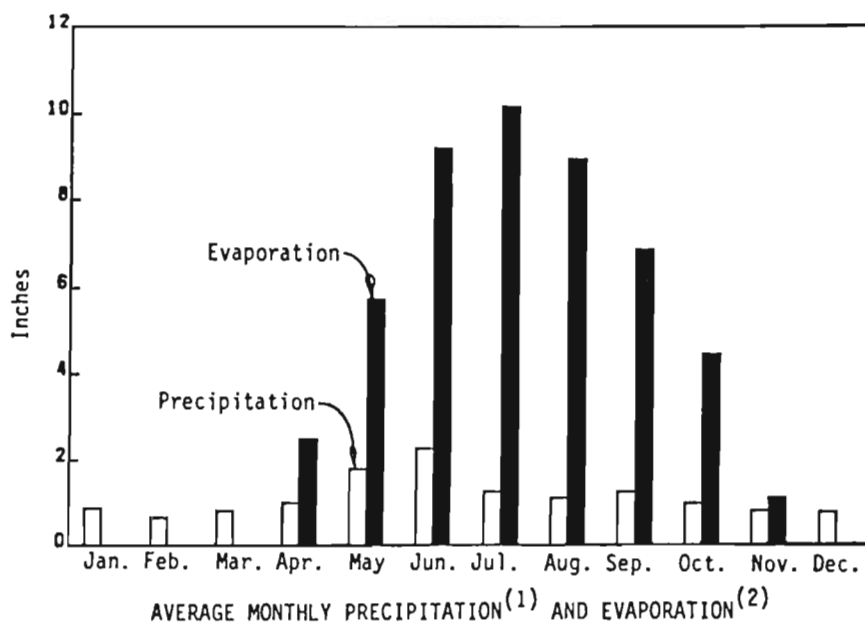
(1) Data from 1906 through 1978
(2) Data from 1974 through 1978, Class A Pan

SOURCE: HYDROMETRICS, 1984

Figure 2.   Climatological data for east Anaconda.

Mean monthly temperatures range from 22.0° F in January to 65.6° F in July and average daily temperatures are normally above freezing during the months April through November. Precipitation ranges from a monthly mean of 2.27 inches in July to 0.65 inches in February; the annual mean is 13.52 inches. Pan evaporation was measured during the summer months in 1974 through 1978. Average pan evaporation for the months April through November was approximately 49 inches.

Wind data from the Weather Hill meteorological station between January, 1978, and January, 1979 (except for the summer months) indicate that prevailing winds are from the west-southwest to west-northwest for all months. Average such winds occurred over the study period, 48 percent of the time and ranged from 31 percent (November) to 59 percent (September). Averaged over the study period, winds from the west occurred 26 percent of the time, and ranged from 20 percent (November) to 40 percent (October). Winds from the east to south occurred an average of 23 percent of the time and ranged from 15 percent (May) to 34 percent (September). Distribution of predominant winds did not indicate a seasonal pattern for the months concerned. Least common winds were generally from the north-northwest to northeast. Average maximum monthly wind speeds were from the south to southwest and west-northwest. The lowest average monthly wind speeds occurred in the directions of the least common winds. However, wind patterns at elevated sites (e.g., the Weather Hill site) may differ from those in the lower valley. Average and maximum wind velocities for 1906-1945 as reported by Anaconda Minerals Company (Davidson 1956) are shown in Table 1.

HYDROGEOLOGY

Geology of the Deer Lodge Valley has been described by Konizeski et al. (1968). Marginal to and underlying the valley are bedrock strata ranging in age from Precambrian to Tertiary. As shown in Figure 3, bedrock formations are prominent around the valley margins and include Precambrian metamorphic and sedimentary rocks, and Paleozoic and Mesozoic sedimentary rocks. Semi-consolidated and consolidated rocks of Tertiary age overlie bedrock and are mantled by unconsolidated alluvium of Quaternary age. A summary of geological units of importance in the basin is presented in Table 2.

TABLE 1. AVERAGE AND MAXIMUM (1 h) MONTHLY WIND VELOCITY
(AVERAGES FOR 1906-1945). MILES PER HOUR (CORRECTED)
(THE VELOCITY FOR 1 O'CLOCK IS THE READING FROM 12:30-1:30, ETC.)

Month	Average	Maximum
January	22.83	65.00
February	20.22	60.13
March	19.52	61.33
April	16.81	55.91
May	15.10	54.60
June	14.98	54.84
July	13.48	54.36
August	13.62	51.34
September	14.41	52.97
October	16.44	53.31
November	20.66	61.98
December	23.03	63.70
Average	17.59	57.45

Reference: Davidson 1956.

Figure 3. Hydrologic and Geologic features of the Opportunity and Anaconda Tailings Pond area.

TABLE 2.   GEOLOGICAL AND WATER-BEARING CHARACTERISTICS OF UNITS IN THE
OPPORTUNITY AND WARM SPRINGS POND AREAS

AGE AND UNIT	ESTIMATED THICKNESS FEET	LITHOLOGIC CHARACTER	WATER-BEARING CHARACTERISTICS
Quaternary Deposits			
Alluvial Fans	0-100	Lenses and layers of sand, silt, clay and gravel. Thickest near canyon mouths.	Low to high permeability. Unconsolidated sand and gravel zones transmit significant quantities of water.
Flood-Plain	0-40?	Mixtures and beds of gravel, sand, silt and clay. Some thin caliche layers.	Low to high permeability. Sand and gravel zones will transmit significant quantities of water.
Tertiary Deposits			
Pliocene	>300	Colluvium, alluvial fans and flood-plain deposits. Layers and lenses of gravel, sand, silt and clay.	Low to high permeability. Sand and gravel zones transmit considerable groundwater.
Miocene	>350	Layers and lenses of silt, sand, conglomerate and lacustrine silt and clay.	Fine-grained materials have low permeabilities. Sand and gravel zones have moderate to high permeability.
Pre-Miocene to Precambrian Bedrock	Several Thousand	Igneous, metamorphic and sedimentary rocks.	Widely variable.

Reference: Konizeski et al. (1968) compiled by Hydrometrics (1983).

Water table elevation data (Hydrometrics 1983a) collected from 1973 to 1982 indicate that groundwater flow is to the northeast, from Smelter Hill to the Opportunity ponds system. A potentiometric map of groundwater contours was developed by Konizeski et al. (Figure 3) and indicates a north-eastward water table slope of approximately 50 ft/mi toward the Clark Fork River.

There are few monitoring wells in the vicinity of the slag pile. The closest Anaconda groundwater monitoring wells with water table elevation data are well Nos. 18 and 49 located across Highway 10A near the Arbiter Plant, and well Nos. 35, 36, 40, and 43 located in or near the Anaconda tailings pond adjacent (east) to the slag pile (Figure 3). Monitoring data from these wells correlate fairly well with the groundwater contours, shown on Figure 3 and using these data, the estimated groundwater elevation under the slag pile is from 5,125 ft to greater than 5,200 ft. The wells located in the Anaconda tailings ponds adjacent to the slag pile (Well Nos. 40 through 43) gave water table elevations consistently higher (greater than 5,200 ft) than those shown on the contour map (Figure 3). However, data for well Nos. 35 through 38 at the base of the Anaconda tailings ponds correlated well with map contours. These data indicate that the presence of the tailings ponds may be affecting the water table elevation for wells 40 through 43. If this is the case, wells Nos. 40 and 43 may not be giving representative values for water table elevations under the slag pile. There are no monitoring wells with long term data located up gradient or directly downgradient from the slag pile.

Seasonal fluctuations for the monitoring wells, nearest the slag pile varied from 7 to 16 ft for well Nos. 18, 34, and 49 located across the highway to 16 to 19 ft for well Nos. 40 and 43 east of the slag pile. Water level (below the ground surface) for these wells ranges from 24 to 34 ft for wells 18 and 34, from 30 to 47 ft for well 49, and from 7 to 30 ft for wells 40 and 43. Again it appears that groundwater flow is affected by the Anaconda tailings ponds and that water is traveling through or being held in the Anaconda tailings ponds. Away from the direct influence of the tailings ponds, typical water level fluctuations seem to be approximately

10 to 30 ft with depths below ground surface of approximately 24 to 75 ft. Well No. 98 was drilled in late February and is located on the railroad grade between the slag pile and Smelter Hill. March water levels for this well ranged from 81.6 to 81.8 ft below the top of the well casing indicating that the water table may be quite deep in the upgradient direction from the slag pile. From these data, the regional water table depth under the slag pile may vary from approximately 24 to 75 ft below the surface of the alluvium underlying the pile.

SURFACE WATER

The regional surface hydrology consists of ephemeral tributaries to Mill Creek and Warm Springs Creek (Figure 4). Mill Creek flows northeast into Silver Bow Creek; Warm Springs Creek joins Silver Bow Creek below the Warm Springs Ponds to form the Clark Fork River. Runoff from the Anaconda Reduction and Opportunity pond systems is diverted into a number of ditches that flow through or are adjacent to the Opportunity tailings ponds and discharge to the Warm Spring Pond system. Mill Creek, Warm Springs Creek, Silver Bow Creek, and the Clark Fork River are perennial streams (Hydrometrics 1984).

The Smelter Hill area is drained by the aqueduct which flows into the Opportunity tailings pond system. The south sewerage ditch from Anaconda flows along the north side of the slag pile between the pile and Highway 10A. This sewerage ditch also flows into the Opportunity tailings pond system (B2 ponds). Drainage from the pond system eventually flows to the Warm Springs ponds and then to the headwaters of the Clark Fork River.

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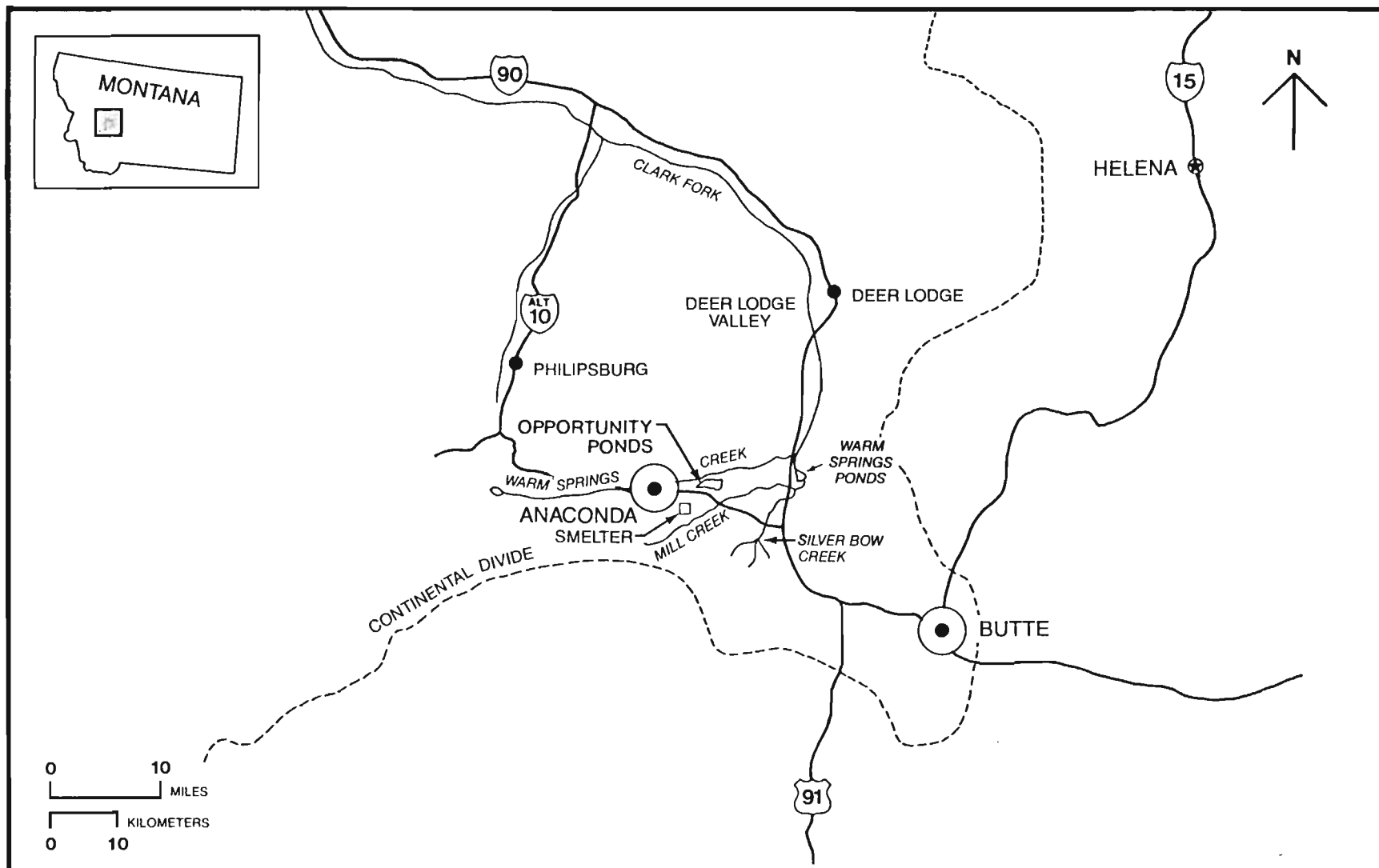
Figure 4. Anaconda vicinity map.

III. WASTE TYPES AND QUANTITIES

The slag pile consists of coarse, granular slag produced as a waste product in the reverberatory copper smelting process. There is little historical data on the metals composition of the slag. Data from recent analyses, summarized by Tetra Tech (1985), indicate the presence of several metals and sulfur in the slag.

The area and volume of the slag pile were calculated to be 130 acres and 16 million yd^3, respectively. These values were calculated using contour and distance information from the Anaconda Smelter Site map compiled by Horizons, Inc. from aerial photographs taken on November 8, 1984. The mass of the slag pile was estimated (assuming an average density of 1.96 g/cm^3) to be 26.5 million tons.

IV. DISCUSSION OF FIELD AND ANALYTICAL LABORATORY RESULTS

PHYSICAL AND CHEMICAL CHARACTERISTICS OF SLAG

Results of the physical and chemical analyses of the slag were reported in the data report (Tetra Tech 1985), which is included as Appendix A of this report.

The variability in the metal concentrations among the 10 slag samples analyzed is summarized in Table 3. Coefficients of variation among stations for the detected metals range from a low of 14.7 for iron to a high of 162.5 for silver. Based on a blind triplicate submitted to the laboratory, analytical precision (expressed as coefficient of variation) for the detected metals ranged from 0.4 to 11.9 (see Appendix A). The calculated analytical precision (coefficient of variation) for the majority of the detected metals (14 of 18) ranged from 2.3 to 4.2. Therefore, a substantial amount of the variability in slag metals concentrations cannot be attributed to the precision of the analytical method. The variability in the slag metals concentrations among sampling locations may be due to different ores used over the years in the smelting process, changes in the smelting process with time.

Results of the slag sieve analyses indicate that the material is quite coarse and there is minimal variation in grain size distribution among samples. Figure 5 shows the grain size distributions for all 10 samples. A majority of the slag sampled (40 to 92 percent by weight depending on location) may be classified within the coarse and very coarse sand size classification (Folk 1968). From 75 to 97 percent of the slag is coarser than the medium sand size classification.

Photomicrographs of slag particles were taken by the Department of Geological Sciences at the University of Colorado (Boulder, Colorado) using a scanning electron microscope. Figures 6 through 8 show the characteristics

TABLE 3. VARIABILITY OF SLAG CHEMICAL CHARACTERISTICS

Parameter	Range	Mean[a]	Standard Deviation	Coefficient of Variation[a]
Acid Extractable Metals (mg/kg dry weight basis)				
Aluminum	17,100-30,700	21,690	3,836	17.
Antimony	42-219	111	53	47.7
Arsenic	498-3,190	1,978	800	40.4
Barium	266-3,190	1,180	846	71.7
Beryllium[b]	<2.5-2.7	2.5	0.06	2.4
Boron	<8.0-170	33	48.5	147
Cadmium	4.4-44	22.8	10.9	47.8
Chromium	45-436	271	125	46.1
Cobalt	28-517	142	147	103.5
Copper	3,140-9,760	6,271	1,831	29.2
Iron	188,000-341,000	307,500	45,078	14.7
Lead	364-4,310	2,044	1,413	69.1
Manganese	710-17,200	3,373	5,376	159.4
Mercury[b]	<0.04-0.08	0.04	0.013	32.5
Molybdenum	<3-670	151	231	153.0
Nickel	<20-291	71	84	118.3
Selenium[b]	<50-85	54	11	20.4
Silver	<5.0-88	16	26	162.5
Tin	<20-220	101	66	65.3
Vanadium	83-229	156	52	33.1
Zinc	8,380-36,300	26,198	8,330	31.8
Total sulfur (%S, dry weight basis)	0.51-1.36	1.10	0.26	23.6
Pyritic sulfur (%S, dry weight basis)[c]	<0.01	<0.01	0.0	0.0
pH (1:1 slurry)	6.4-8.9	--	--	--

[a] The detection limit was used for values reported as less than the detection limit.

[b] Nine of the 10 values reported are less than the detection limit.

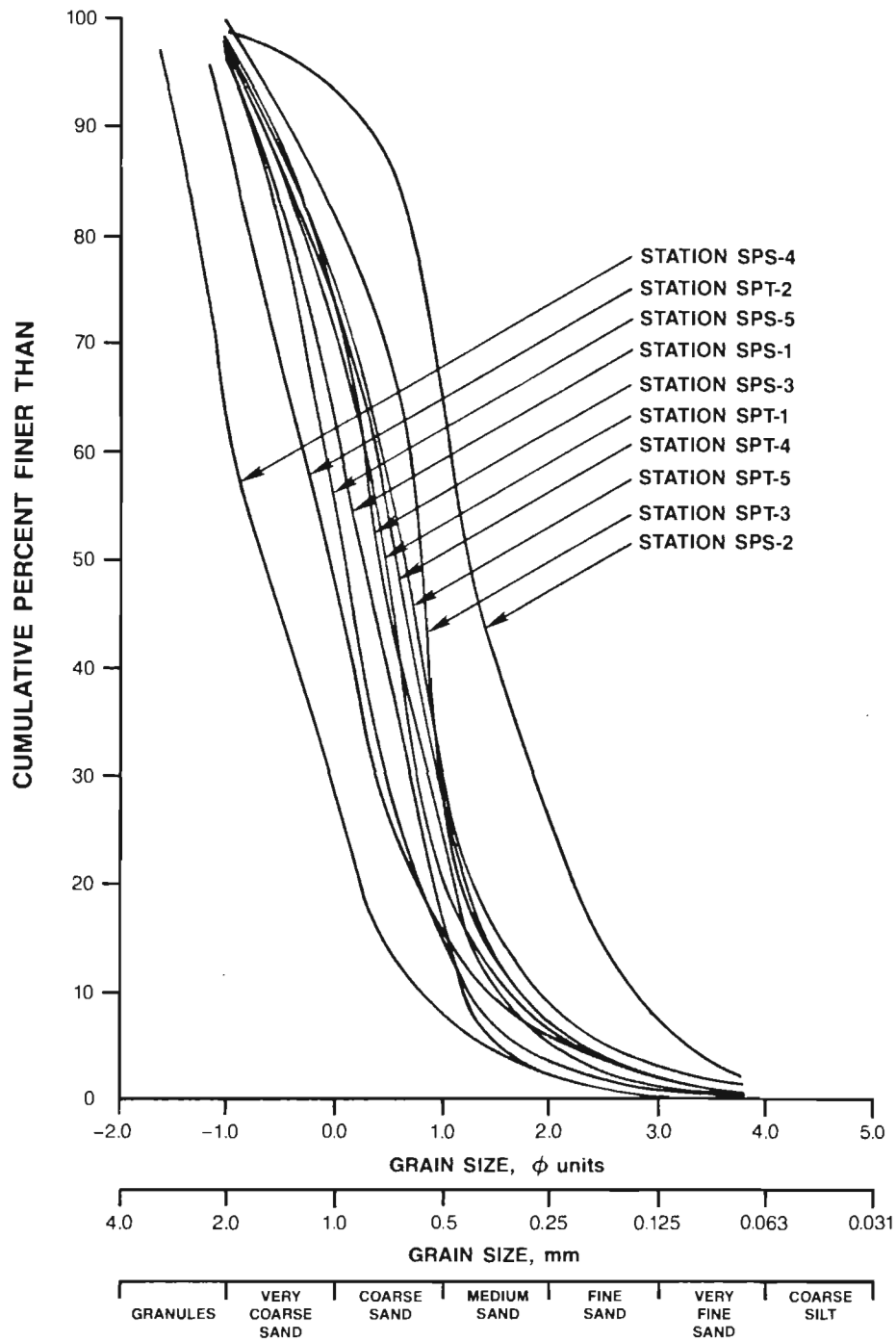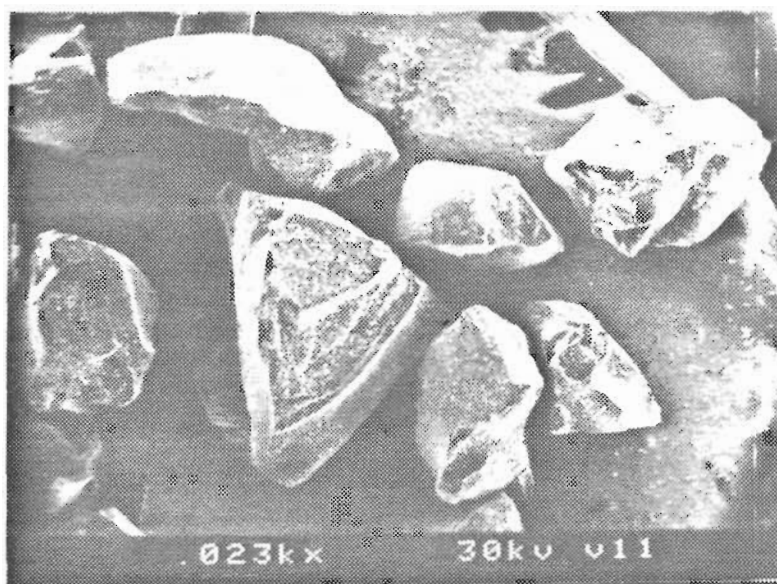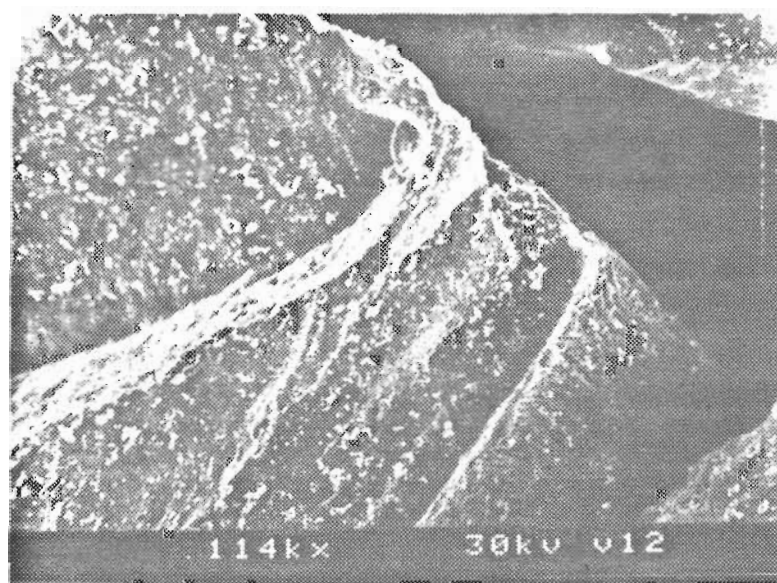[c] All 10 values were reported as <0.01.

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Figure 5. Grain size distribution of slag samples.
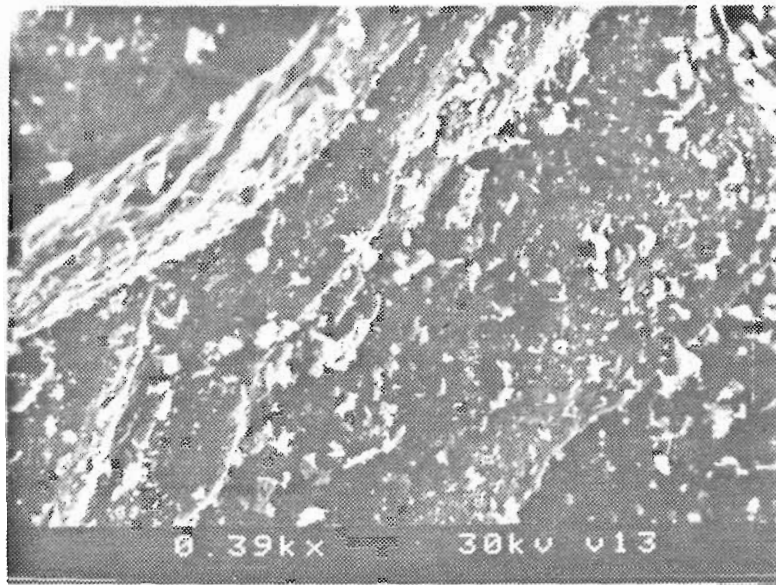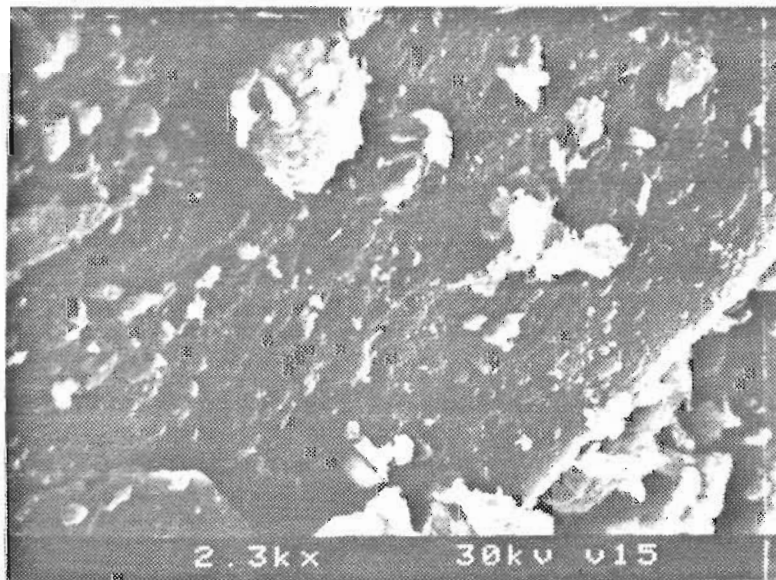
23x

114x

Figure 6.   Photomicrographs of slag particles at magnifications of 23x and 114x.
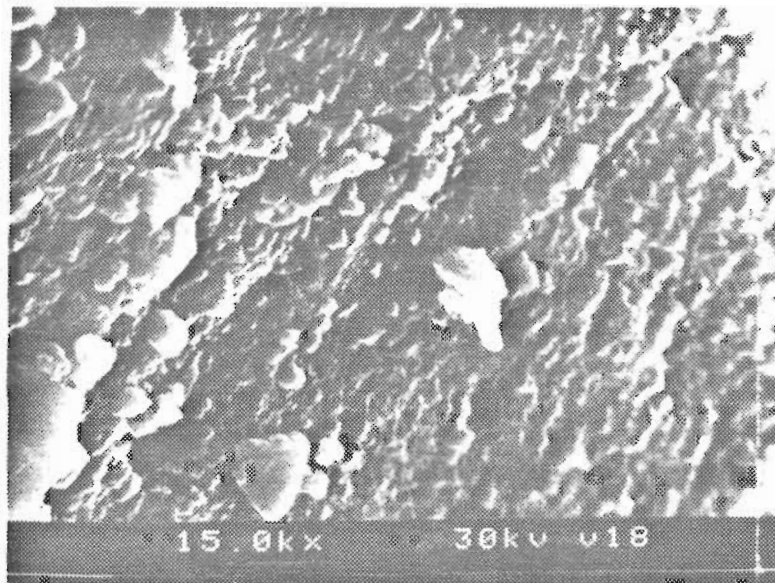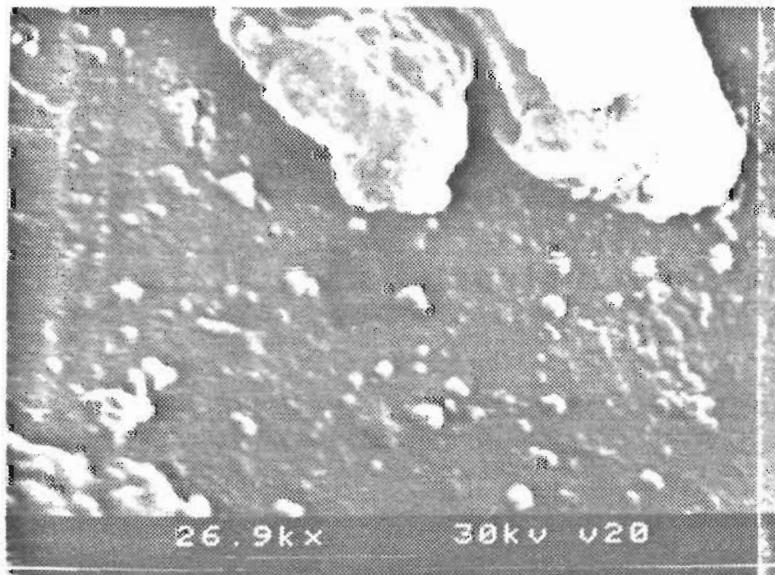
390x

2300x

Figure 7. Photomicrographs of slag particles at magnifications of 390x and 2300x.

15,000x

26,900x

Figure 8. Photomicrographs of slag particles at magnifications of 15,000x and 26,900x.

of slag particle surfaces at various magnifications. These figures indicate that the slag particles are not porous but are solid, amorphous particles. Visual inspection of the slag reveals that it is composed of coarse grained, black particles with a vitreous luster.

SLAG LEACHATE CHARACTERISTICS

Leachate column tests were performed using Anaconda Smelter slag as described in the FOP (Tetra Tech 1984) to assess the potential for migration of metals in leachate from the slag pile. Results were reported in the data report (Tetra Tech 1985), which is included as Appendix A of this report.

Antimony, arsenic, iron, selenium, and silver were generally not detected or detected in small quantities in the leachate and are not considered further. Figures 9 through 11 show the relationships between the detected leachate metals concentration (cadmium, copper, lead, manganese, and zinc) and pore volume number (or time). The plotted concentrations are not corrected for the blank, however, the concentration in the blank is shown on each figure. As shown in these graphs, cadmium and zinc concentrations in the leachate peaked in the second pore volume with a gradual decrease in concentration throughout the rest of the test to the 25th pore volume. Lead concentration increased gradually throughout both column tests showing no evidence of leveling out or decreasing by the 25th pore volume. Manganese concentrations also peaked in the second pore volume and leveled out between 35 and 45 ug/L by the 25th pore volume. Copper concentrations increased gradually until the 10th and 15th pore volumes and then leveled out at approximately 10,000 ug/L by pore volume 25.

Figures 11 and 12 show the relationships between sulfate, pH, and specific conductance; and pore volume number. All three of these parameters peaked in the first pore volume. Sulfate concentrations leveled out at a value near the detection limit (0.5 mg/L) from the 5th through 25th pore volumes. The pH gradually decreased from a value of 7.2 to 7.6 in the 1st pore volume to 6.3 to 6.4 in the 25th pore volume. Specific conductance
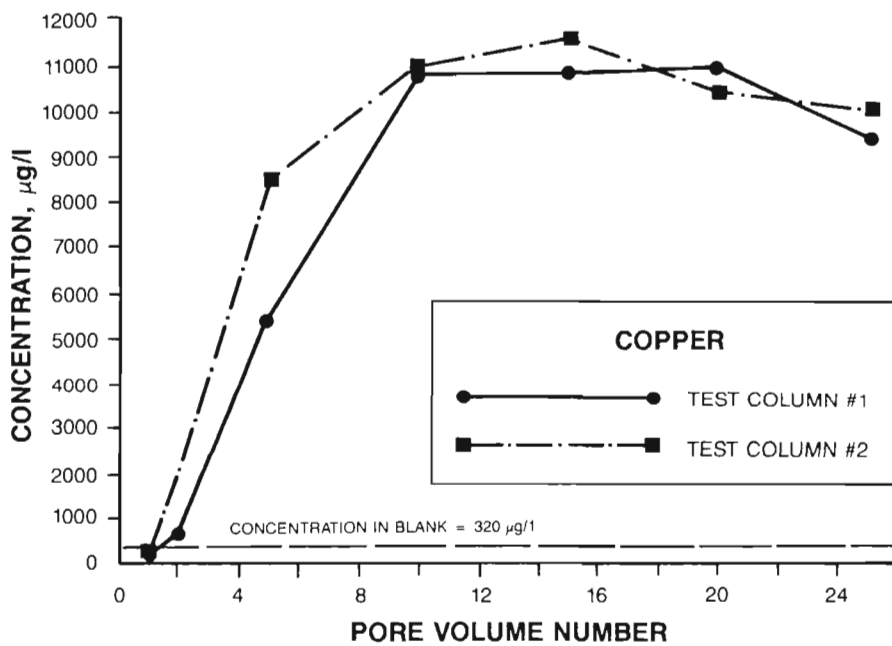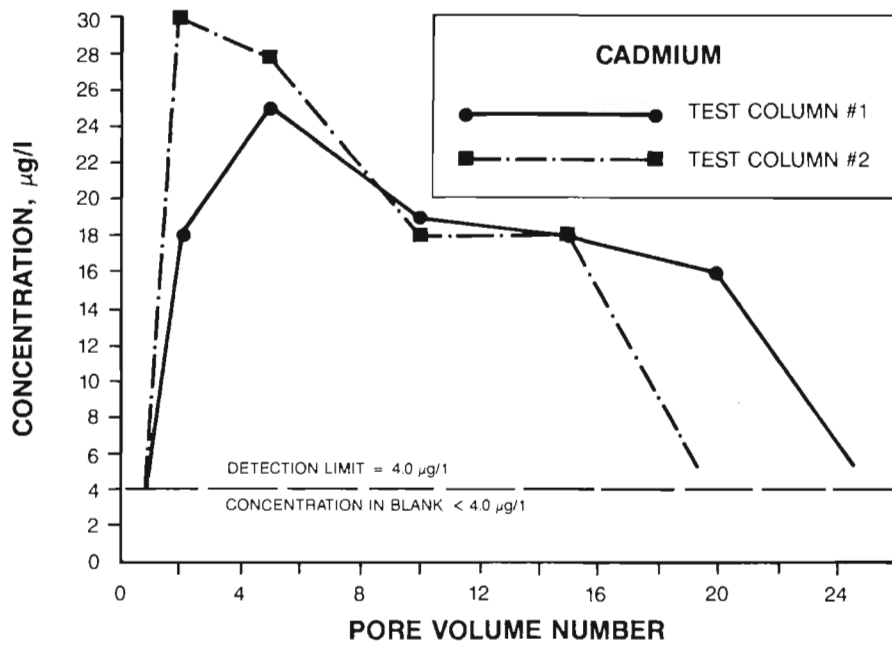
Figure 9.   Leachate cadmium and copper concentrations versus pore volume number.
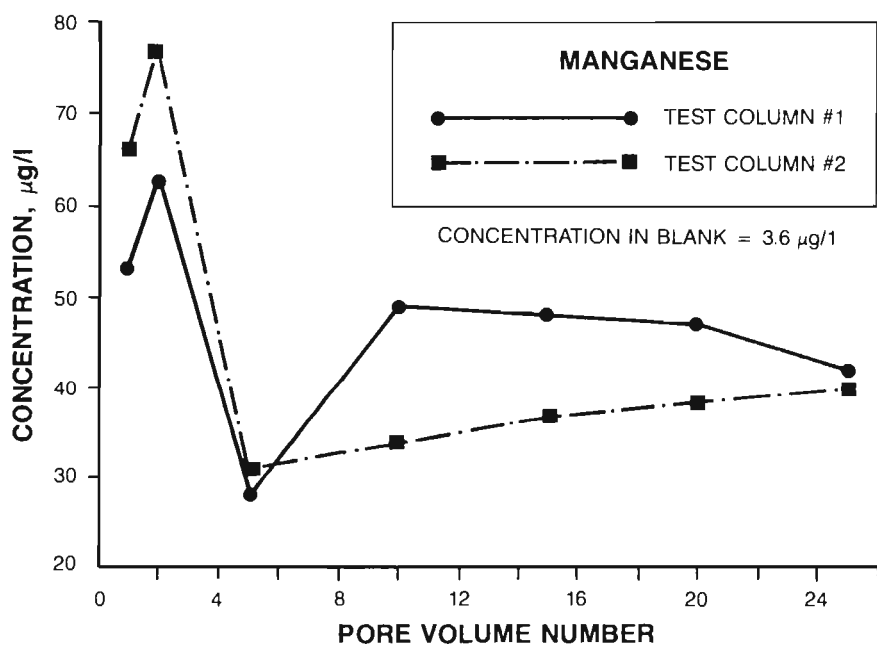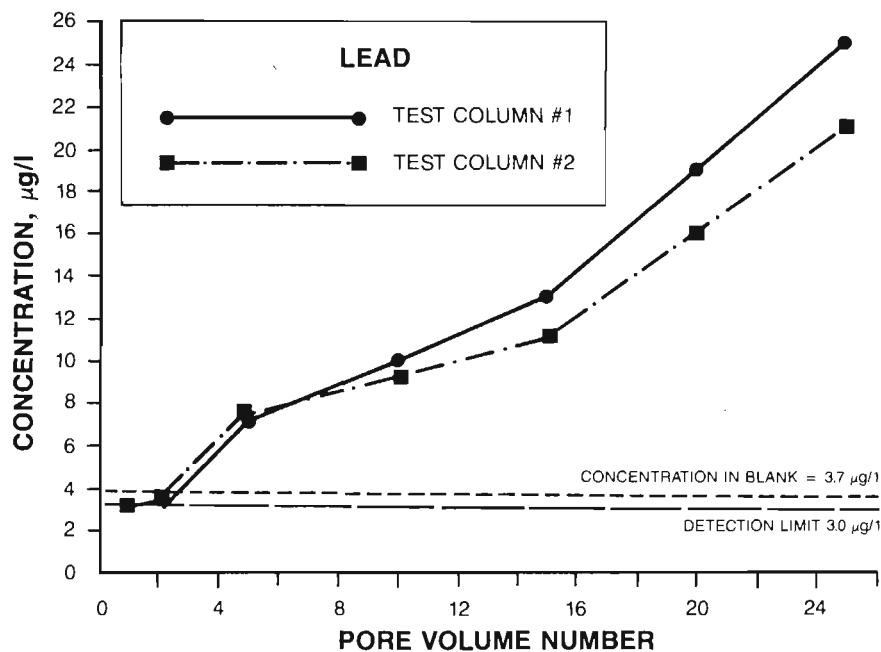
Figure 10. Leachate lead and manganese concentrations versus pore volume number.
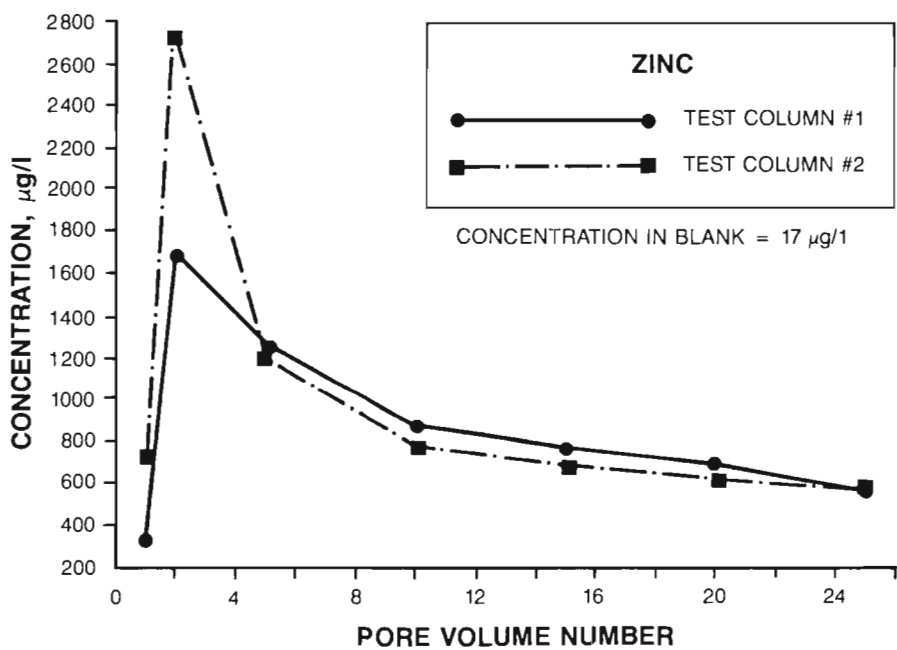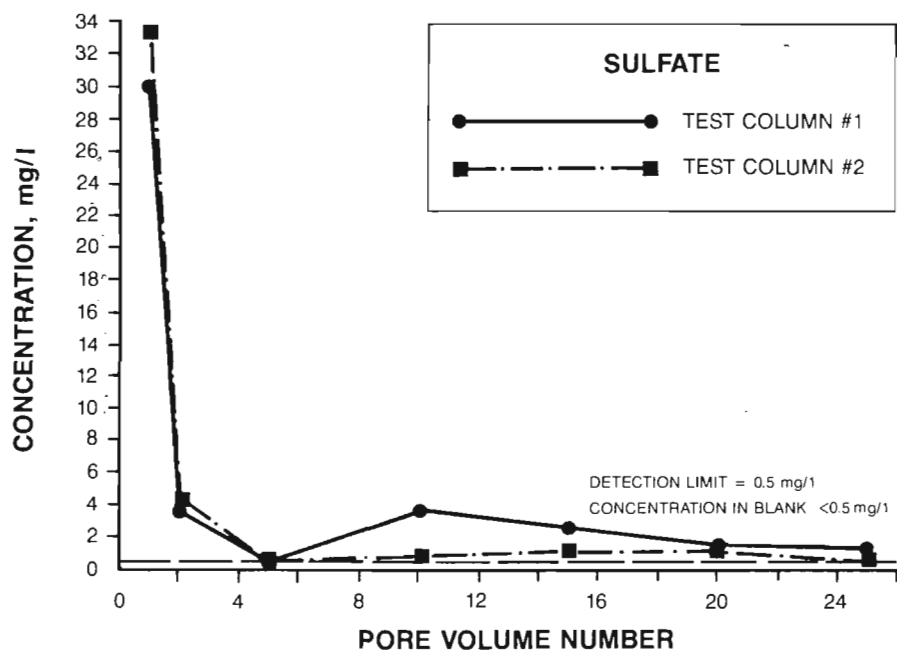
Figure 11. Leachate sulfate and zinc concentrations versus pore volume number.
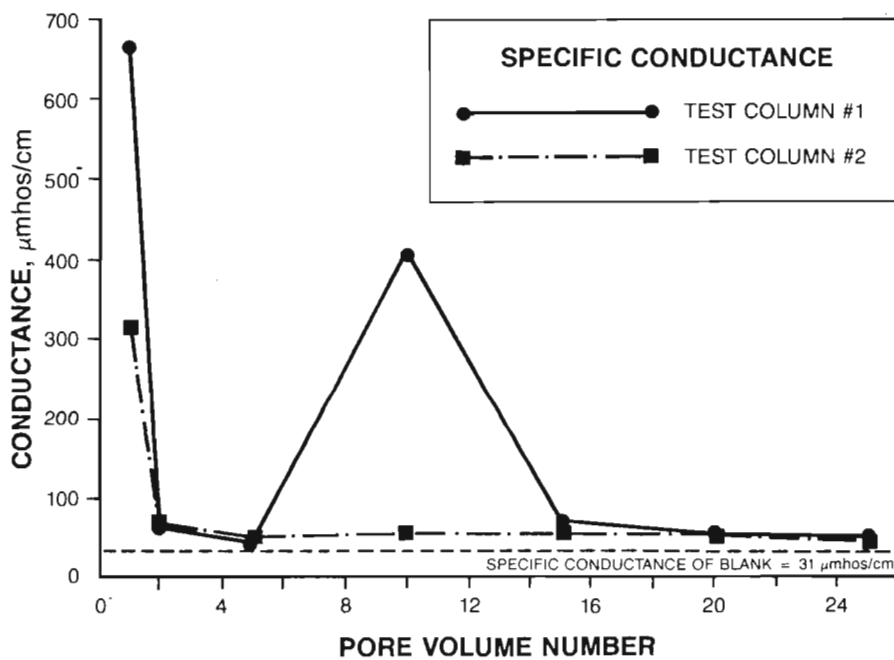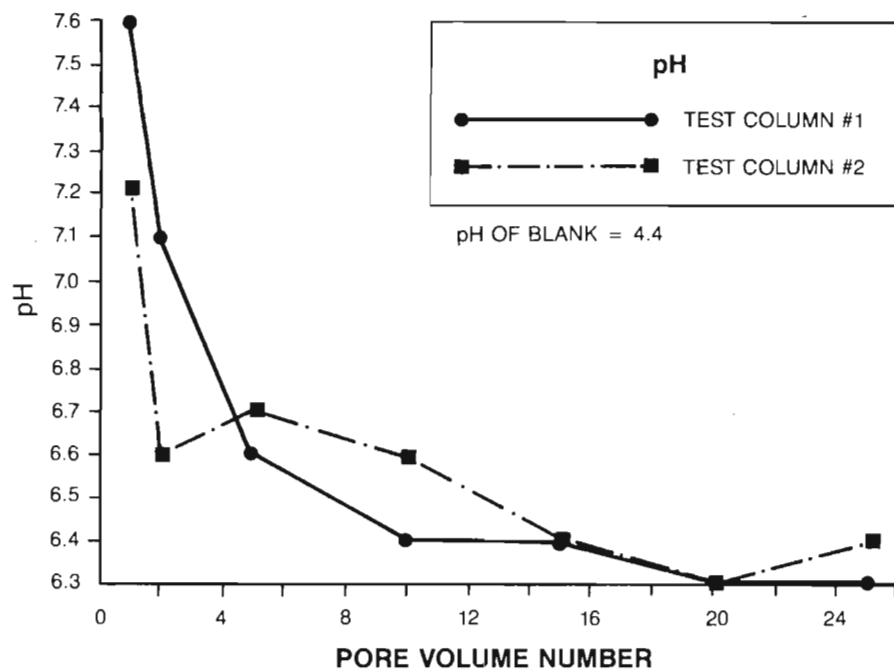
Figure 12. Leachate pH and specific conductance versus pore
volume number.

decreased sharply in the 2nd pore volume and leveled out at approximately 50 umhos/cm for the 10th through 25th pore volumes.

The relationships between the amount of metals leached from the columns during 25 pore volumes and the total metals concentrations measured in the slag is summarized in Table 4. The percent of material leached in 25 pore volumes varies from a high of 0.6 for copper to a low of 0.002 for lead. These results indicate that the metals in the slag are not readily available for leaching.

These results indicate that there is potential for leaching of small amounts of pollutants from the slag material into solution during rainfall events. The highest pollutant concentrations were typically measured in the first few pore volumes (pore volumes 1 through 5) of both column tests. Copper, iron, and lead concentrations in the leachate were higher in the later pore volumes (pore volumes 15 through 25).

Whether this small amount of metals leaching poses an environmental or health risk is discussed later in this report. However, it should be noted that it is very difficult to extrapolate the results of the leachate column tests to actual field processes due to differences between rainwater pH and leaching solution pH, vertical density stratification of the slag pile and the leachate column, and solution detention time through the leachate column and the slag pile. The metals concentrations measured in the leachate should be much higher than those expected under field conditions because the leaching solution used in the leachate column tests had a pH ranging from 4.2 to 4.4, which is more acidic than rain. Generally, the solubility of most metals increases as the pH decreases. Therefore, lower metals concentrations would be expected in leachate in the field.

For criteria evaluation, the slag leachate column tests conducted during the investigation are most similar to the Extraction Procedure (EP) Toxicity test which is designed to simulate the leaching that a waste could undergo if placed in a landfill. Results of EP Toxicity tests are compared to maximum contaminant levels given in 40 CFR 261.24 which represent 100 times the national primary drinking water criteria (discussed in Section VI).

TABLE 4. PERCENT LEACHED DURING LEACHATE COLUMN TESTS

Metal	Mean Slag Concentration (mg/kg)	Total Leached[a] (ug)		Percent Leached[b]	
		Column #1	Column #2	Column #1	Column #2
Cadmium	22.8	927	810	0.24	0.20
Copper	6,271	621,222	678,075	0.58	0.61
Lead	2,044	677	575	0.002	0.002
Manganese	3,373	3,141	2,757	0.006	0.005
Zinc	26,198	65,148	68,349	0.015	0.015

[a] The total mass leached in 25 pore volumes was calculated using linear interpolation between measured pore volumes. The detection limit was used for concentrations reported as less than the detection limit. The leachate concentrations were not corrected for the blank.

[b] Percent Leached = 100 x [mass of metal leached in 25 pore volumes/total mass of metal in column].

If the maximum pollutant concentrations measured in the slag column test leachate are compared to the EP Toxicity criteria, all pollutant concentrations are lower than these criteria by at least an order of magnitude. Using similar criteria for the secondary pollutants (100 times the national secondary drinking water criteria), all maximum leachate pollutant concentrations are lower than these criteria by at least an order of magnitude.

V. EVALUATION OF POTENTIAL PATHWAYS OF POLLUTANT RELEASE

GENERATION OF AIRBORNE PARTICULATES

Generation of airborne particulates is not expected to be a problem with the slag. Minimal air transport of slag particles was observed during field activities conducted during periods of strong winds. Site reconnaissance showed little evidence of transported slag particles to the east or northeast (most common wind direction), in the margin between the slag pile and the highway. Even during periods of prolonged snow cover when slag is most easily seen, little slag was observed on or within the snow layer surrounding the slag pile.

In addition, results of sieve analyses indicate that greater than 75 percent of the slag particles sampled can be classified in the coarse to very coarse sand size classification based on grain size. Net transport of particles of this size by wind is considered negligible.

In view of these data, generation of airborne particulates from the slag pile is considered negligible. Therefore, no further analysis will be conducted.

SURFACE RUNOFF

Surface runoff from the slag pile is expected to be minimal because of the relatively large size of the slag particles. Recorded field observations indicate no sign of erosion, surface runoff channels, or slag redistribution due to the presence of water or water movement.

Using results of the sieve analyses, the hydraulic conductivity (co-efficient of permeability) of the slag was estimated using the following relationship (Masch and Denny 1966):

$$\sigma_I = \frac{d_{16} - d_{84}}{4} + \frac{d_5 - d_{95}}{6.6}$$

where:

σ_I = inclusive standard deviation

d_i = i percentile grain diameter, ϕ units

The hydraulic conductivity may be estimated using the inclusive standard deviation, the 50 percentile grain diameter and Figure 13. For the ten slag samples (see Figure 5), the estimated hydraulic conductivity ranged from approximately 460 to 1900 gal day^{-1} ft^{-2} which is equivalent to 0.022 to 0.090 cm/sec. These data indicate that the slag is a very permeable material with a hydraulic conductivity on the order of that of clean sand (Table 5) (Freeze and Cherry 1979).

To determine the potential for surface runoff, the hydraulic conductivity of the material may be compared to the rainfall rates during intense storm events. The 1-h precipitation for the 100-yr return period was selected to represent an intense storm event. The 1-h rainfall for this storm was calculated to be 0.65 inches using the relationships developed by Miller et al. (1973). Therefore, the rainfall rate for this event is on the order of 10^{-4} cm/sec. Comparing this rate (10^{-4} cm/sec) to the minimum hydraulic conductivity (10^{-2} cm/sec) reveals that the slag pile is certainly capable of conducting all of the water from this intense storm event therefore, precluding surface runoff. However, if surface runoff were to occur, the drainage from the slag pile would be collected in the aqueduct or the south sewerage ditch, both of which flow into the Opportunity tailings pond system. There are no other nearby surface waters.

Given the magnitude of the calculated hydraulic conductivity of the slag material and the estimated rainfall rate for a representative intense storm event, negligible surface runoff volume is predicted. Therefore, no additional analysis of surface runoff from the slag pile will be conducted. Since no visible signs of surface water runoff were observed during site

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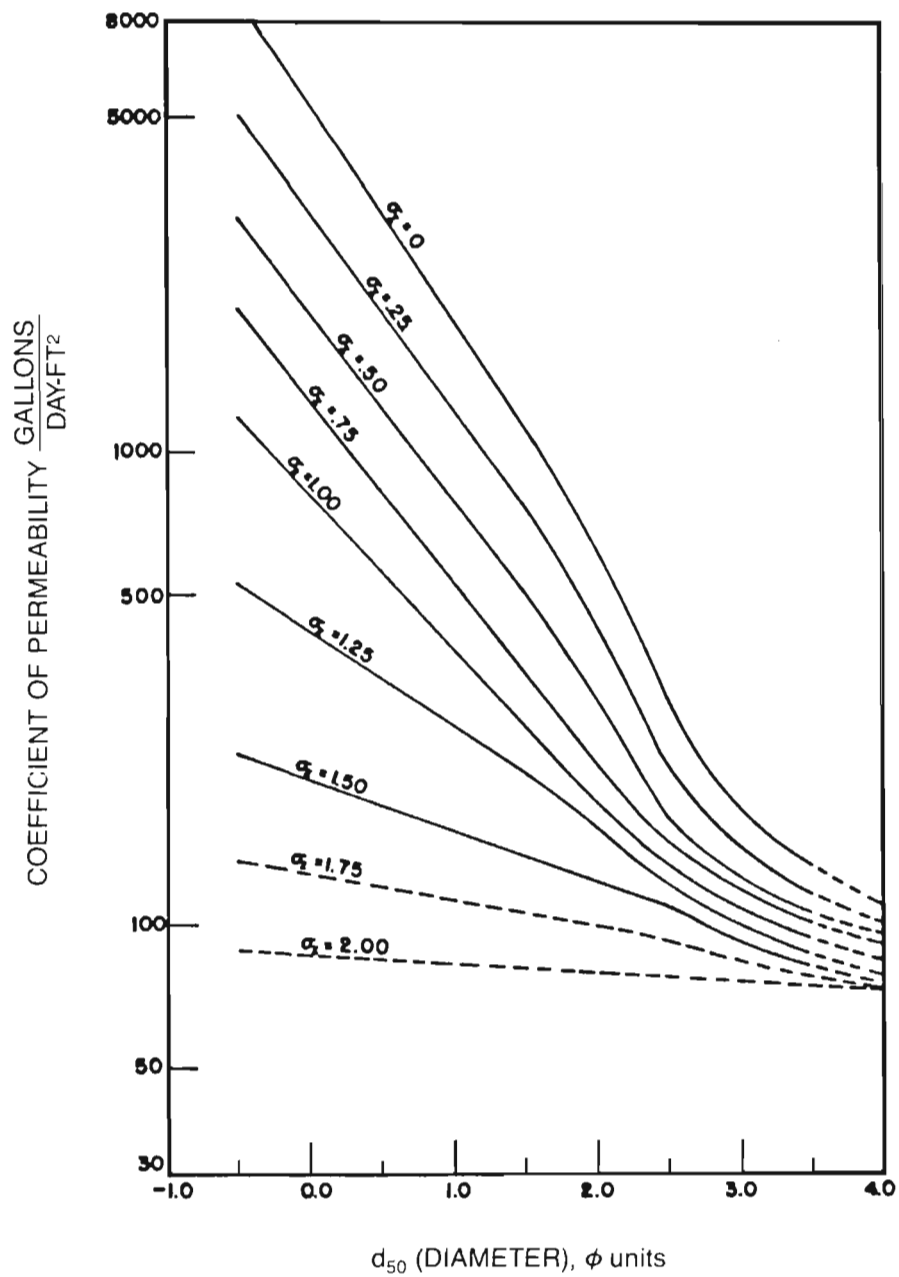
Figure 13. Curves used for predicting coefficient of permeability.

TABLE 5. RANGE OF VALUES OF HYDRAULIC CONDUCTIVITY FOR VARIOUS MATERIALS AND ANACONDA SMELTER SLAG

REFERENCE: FREEZE AND CHERRY, 1979

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reconnaissance (see Appendix A) and results discussed above indicate little probability of surface water runoff from the slag pile, the surface water sampling program for the slag pile [as discussed in the final work plan (CH2M HILL 1984) and the field operations plan (Tetra Tech 1984)] will not be conducted.

GROUNDWATER

The potential for groundwater contamination by metals may be determined by evaluating the mobility of metals in soil, the depth of the aquifier, and existing upgradient and downgradient groundwater quality data.

Mobility of Metals in Soils

The rate and magnitude of leaching of metals and other contaminants into groundwater depends on the mobility of the contaminants in the soil. Soil characteristics that have been found to influence mobility of metals include soil mineralogy (clay content), free iron oxide content, organic matter content, solution flux rate, and soil pH.

Korte et al (1976) evaluated the influence of soil physical and chemical properties on trace element migration. Eleven elements (arsenic, beryllium, cadmium, copper, mercury, nickel, lead, selenium, vanadium, and zinc) were applied to 11 soils (column leaching tests) representing seven soil orders and a variety of textural classes. Six soil parameters (i.e., clay content, pH, cation exchange capacity, surface area, free iron oxides, and Mn concentration) were evaluated for their statistical correlation with metal migration. It was concluded that a linear regression equation using percent clay, surface area, and percent free iron oxides as the independent variables may be used to predict the amount of absorbed cadmium, beryllium, zinc, and nickel with significance at the 99 percent confidence level. The inclusion of pH as a variable did not significantly improve the reliability of the equation for these metals.

In a related investigation, Alesii et al. (1980) studied the effect of leachate flow rates on metal migration through soil. Municipal solid

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waste leachates individually enriched with beryllium, cadmium, chromium, iron, nickel, and zinc were used to perfuse nine soils representing seven major soil orders (the same soil types as those used by Korte et al. 1976). Soils retention of cadmium, nickel and zinc were very similar. Beryllium and chromium mobility was found to be sensitive to changes in flux (leachate throughput rate). The metal concentration in the leachate and the clay content of the soil influenced the metal retention by the soil more than any other factors considered.

Of the metals considered in the slag investigation, only iron, cadmium, copper, lead, manganese, zinc, and arsenic were detected in both the slag and the leachate. Research results summarized by Battelle (1984) cover factors influencing the mobility of each of these metals. Soil adsorption of arsenic, cadmium, copper, and zinc is strongly controlled by the presence of oxides (manganese, iron, or aluminum oxides). Arsenic is strongly adsorbed by most soils or sediments. Adsorption of cadmium is also related to the cation exchange capacity (CEC). Copper and lead are strongly adsorbed by soil organic matter. Precipitation reactions are an important removal mechanism for copper (at pH>6.5), cadmium (at pH>7.0), iron, and lead. Soil properties correlated with lead adsorption by soil include soil organic matter and clay content. Little information is available on mobility of manganese in soil.

Based on information in the literature, Fuller (1977) classified the mobility in soils under aerobic conditions of 10 metals as follows:

- Relatively mobile - selenium

- Moderately mobile - iron, zinc, lead, copper, and beryllium

- Slowly mobile - arsenic, cadmium, chromium, and mercury.

Information in the literature on metals mobility under anaerobic conditions is very limited. At the University of Arizona, municipal landfill leachate was spiked singly with trace metals and passed through columns of disturbed soils maintained in anaerobic conditions. Based on these results, Fuller

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(1977) grouped the mobility of selected metals in acid and neutral to alkaline soils as shown in Table 6.

The pH of 11 alluvium samples collected at four sites just outside the Opportunity tailings ponds was measured by Hydrometrics (1983b). The soil pH ranged from 5.6 to 7.3 with a majority of soil pHs (9 of 11) greater than 6.0. Based on these limited data the alluvium at the Anaconda smelter site can be classified as a neutral to alkaline soil with the associated metal mobility as described in Table 6.

In summary, available research results indicate that the mobility of the detected metals in most soils (particularly those with significant clay, oxide, and organic content) can be characterized as low to medium depending on whether aerobic or anaerobic conditions prevail.

Aquifer Depth

Water table elevation data (Hydrometrics 1983a) in the vicinity of the slag pile were reviewed in the hydrogeology section of this RI report. These data indicate that at a minimum, the aquifer in the vicinity of the slag pile is approximately 20 to 30 ft below the surface of the alluvium and may be as deep as 80 ft. Vertical mobility of detected metals has been assessed to be relatively low, however, as an added safety factor, 20 to 80 feet of alluvium should be adequate to remove and retain metals that may be leaching from the slag pile and into the alluvium. The potential for groundwater contamination by metals is considered further by evaluating existing groundwater quality data from monitoring wells near the slag pile.

Groundwater Quality

Both upgradient and downgradient groundwater quality data (metals concentrations) were evaluated to determine the potential for metal con- tamination due to the slag pile in a downgradient direction from the pile. Only one well (No. 98) has been drilled upgradient of the slag pile. Well No. 98 was drilled in late February and early March, 1985 and has only been sampled once (March, 1985) for water quality. It is located on the

TABLE 6. MOBILITY OF METALS IN DIFFERENT ANAEROBIC SOILS

Soil type	pH	Elements in the leachate		
		Relatively mobile	Moderately mobile	Slowly mobile
Acidic soils				
Wagram l.s.	4.2			
Ava si.c.l.	4.5			
Kalkaska s.	4.7	Cadmium Nickel	Arsenic[a]	Copper
Davidson c.	6.2	Mercury	Beryllium	Lead
Molokai c.	6.2	Zinc	Chromium	Selenium[a]
Chalmers si.c.l.	6.6			
Neutral to alkaline soils				
Nicholson si.c.	6.7			
Fanno c.	7.0	Arsenic[a]	Beryllium	Copper
Mohave s.l.	7.3	Chromium[a]	Cadmium	Lead
Mohave$_{Ca}$ c.l.	7.8		Mercury	Nickel
Anthony s.l.	7.8		Selenium[a] Zinc	

[a] Arsenic, selenium, and to a certain extent chromium conform to the above mobility pattern least well. For example, Se was found to move slowly in Fanno c. and relatively fast through Wagram l.s. Arsenic moved slowly through the neutral soils, Nicholson s.c., and Fanno C., and relatively fast through Davidson and Molokai clays. Chromium moved slowly through Davidson c., Nicholson si.c. and Molokai. Thus with those elements which form anions, the effect of clay content in soils is relatively dominant, particularly where the pH ranges near neutral conditions (i.e., mildly acidic or alkaline).

Reference: Fuller (1977).

railroad grade adjacent to the southwest corner of the pile between the slag pile and Smelter Hill. A series of downgradient wells was selected to cover a transect running perpendicular to the groundwater flow to intersect potential contaminant plumes from the slag pile. This transect was described by well Nos. 21, 35, and 36 (Figure 3). Available groundwater quality data (Hydrometrics 1983a) for these wells are summarized in Table 7. These data are for unfiltered samples collected from iadequately developed wells and therefore, provide conservatively high pollutant concentrations (Tillman, R. 20 May 1985, personal communication). The total concentrations summarized in Table 7 represent pollutant contribution from both the dissolved and particle phases. Any comparison using these data are conservative because the actual metal concentrations associated with the groundwater are lower. However, for this analysis, the total concentrations summarized in Table 7 will be used to conservatively represent groundwater quality in the vicinity of the slag pile. Well Nos. 35 and 36 will be sampled twice for water quality (spring and fall) as part of the Anaconda Smelter RI/FS groundwater sampling major investigation subtask. An on-line filtration unit will be used to filter the samples for dissolved metals analyses. The results of these analyses may be used to determine the actual metal concentrations in these wells.

Metals concentrations in groundwater from these wells is quite variable over time. These data indicate that generally, the upgradient groundwater concentrations (well 98) of arsenic, cadmium, copper, manganese, and zinc were higher than the maximum concentrations from wells downgradient (wells 21, 35, and 36) of the slag pile. Maximum downgradient concentrations of lead were approximately twice the concentration of the upgradient well, however, average downgradient lead concentrations were well below the upgradient value. Maximum downgradient iron concentrations were from 2 to 5 times greater than upgradient concentrations. The average downgradient iron concentration was generally much less than the upgradient concentration (one measurement only). These data indicate that the upgradient groundwater metals concentrations are generally higher than the downgradient concentrations suggesting the presence of a pollutant source upgradient (on Smelter Hill) from the slag pile. Downgradient groundwater quality at well Nos. 35 and 36 may be substantially affected by the adjacent Anaconda tailings ponds.

TABLE 7. SUMMARY OF GROUNDWATER QUALITY DATA FOR WELLS NEAR THE SLAG PILE, 1974-1980

	Well #21[b]				Concentration, (mg/L)[a] Well #35				Well #36				
Parameter	Range	Mean	Standard Deviation	Number of Samples	Range	Mean	Standard Deviation	Number of Samples	Range	Mean	Standard Deviation	Number of Samples	Well #98[c]
Arsenic	<0.01-0.02	0.01	0.004	12	<0.01-0.296	0.09	0.074	46	<0.01-0.312	0.06	0.056	54	0.56
Cadmium	<0.002-0.24	0.03	0.067	12	<0.002-0.11	0.01	0.015	46	<0.002-0.188	0.02	0.026	54	0.42
Coppper	<0.06-0.48	0.15	0.113	12	<0.01-0.23	0.04	0.044	47	0.014-0.27	0.06	0.051,	55	1.9
Iron	0.06-25.6	2.59	7.321	12	0.06-21.2	3.63	4.482	45	0.31-99.5	13.67	19.52	53	10.2
Lead	<0.01-0.19	0.03	0.052	12	<0.01-0.12	0.01	0.017	46	<0.01-0.14	0.02	0.029	54	0.07
Manganese	<0.01-1.89	0.22	0.524	13	<0.01-0.24	0.05	0.066	45	0.01-3.69	0.17	0.495	54	0.51
Mercury[d]	<0.00002-0.00005	0.00002	0.00001	12	<0.00002-0.0006	<0.0002	0.0001	46	<0.00002-0.0004	0.0002	0.0001	54	e
Zinc	0.52-16.5	2.09	4.545	12	<0.01-0.82	0.05	0.118	46	0.05-7.45	1.11	1.039	54	49
Sulfate	41-638	118.4	169	12	14-530	103.3	85.4	46	660-1,500	1,104.5	205.7	53	0.79

[a] Concentrations reported as less than the detection limit were taken as the detection limit
to calculate the mean. Values reported are total concentrations.

[b] Measurements were collected from 1973 to 1975 for Well No. 21.

[c] Well 98 has only been measured once (March, 1985).

[d] Mercury detection limits are questionably low.

[e] Data not available.

Reference: Hydrometrics (1983a).

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It is difficult to differentiate between pollutant contribution from the slag pile and contribution from many potential sources upgradient (on Smelter Hill) and downgradient from the slag pile.

Potential for Groundwater Contamination

There is minimal potential for groundwater contamination from metals leaching from the slag pile. The metals detected in the slag and slag leachate appear to have low to medium mobility through the soil. At a minimum, there is an estimated 20 ft of alluvium above the water table in the vicinity of the slag pile with substantial potential for metal retention and adsorption within the soil. Downgradient groundwater quality does not seem to have been substantially affected by contaminant input from the slag pile. Therefore, groundwater contamination associated with metals leaching from the slag pile is estimated to be minimal.

VI. PUBLIC HEALTH AND ENVIRONMENTAL CONCERNS

Public health and environmental concerns regarding the release of pollutants from the slag pile include the following:

- Contamination of nearby towns and adjacent lands by airborne particulates

- Contamination of surface waters and associated toxicity to aquatic life

- Exposure through ingestion of contaminated drinking water (groundwater).

Potential receptors for airborne metal contaminants include the populations of the City of Anaconda (1 mi west of the slag pile), Mill Creek (1.8 mi southeast), Opportunity (3.4 mi east), and Warm Springs (7.1 mi northeast). Based on data for prevailing wind direction, the most common winds (for all seasons) are from the west-northwest to west-southwest. The predominant downwind communities are, therefore, Opportunity and the small community of Mill Creek to the southeast. As demonstrated in the previous section, the possibility of human exposure by airborne metal contamination is extremely remote.

Surface waters in the vicinity of the slag pile include the Smelter Hill drainage aqueduct and the south sewerage ditch from the city of Anaconda. Both the aqueduct and sewerage ditch flow into the Opportunity tailings ponds. As discussed in the previous section, the potential for surface runoff (and subsequent contamination of surface waters) from the slag pile is very small. Therefore, human exposure or environmental impact via this pathway is extremely remote.

The potential for human exposure by groundwater contamination depends on the availability of the source, soil conditions, source proximity to

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groundwater, and the connection between local groundwater and aquifiers used for potable waters. The closest potential receptors for groundwater migration of metals and subsequent uptake through potable well waters are the inhabitants of Mill Creek, located 1.8 mi southwest. However, in the direction of the estimated groundwater flow (to the northeast) the closest receptors are the inhabitants of Warm Springs, located 7.1 mi northeast.

The groundwater quality data for wells near the slag pile (Well Nos. 21, 35, 36, and 98) are compared to drinking water standards as summarized in Table 8. These data indicate that groundwater metals concentrations in the slag pile vicinity are generally lower than the national primary and secondary drinking water criteria (less than 10 percent exceedance) for zinc, copper, mercury and lead. Groundwater concentrations of cadmium exceeded criteria in approximately 18.6 percent of the samples. Similarly, groundwater concentrations of arsenic, manganese, and sulfate exceeded the drinking water criteria in approximately 44 to 50 percent of the samples. Groundwater iron concentrations exceeded the criteria in approximately 85 percent of the samples. It should be noted that the available groundwater data summarized in Table 8 are total metal concentrations from inadequately developed wells. Thus, the well data represent not only the concentration of metals in the groundwater, but also the additional metal concentrations on the particulate matter inadvertently introduced during sampling. The comparison using these data, therefore, are conservative because the actual metal concentrations associated with the groundwater may be much lower.

In terms of groundwater contamination in the vicinity of the slag pile, the pollutants of concern (with respect to drinking water criteria) appear to be arsenic, cadmium, iron, manganese, and sulfate. None of these polluants exceeded EP toxicity criteria in leachate samples from the slag leachate column tests (see Section IV). The concentrations of all measured metals were well below the drinking water criteria at the end of the leachate column tests (25 pore volumes or approximately 2.2 h). These data suggest that in the long-term, the leachable metals from the slag pile will not contribute substantially to groundwater contamination leading to exceedance of drinking water criteria.

TABLE 8. GROUNDWATER TOTAL METAL CONCENTRATIONS AND DRINKING WATER CRITERIA

rameter	Concentration, mg/L[a]		Drinking Water Criteria[b]		
	Downgradient	Upgradient	Maximum Contaminant Level, mg/L	Number of Measurements[c]	Times Exceeded, %
senic	<0.01-0.31	0.56	0.05	113	44.2
dmium	<0.002-0.24	0.42	0.01	113	18.6
pper	<0.01-0.48	1.9	1.0	115	0.9
on	0.06-99.5	10.2	0.3	111	84.7
ad	<0.01-0.19	0.07	0.05	113	8.0
nganese	<0.01-3.69	0.51	0.05	113	49.6
rcury	<0.00002-0.0006	e	0.002	112	0.0
nc	<0.01-16.5	49	5	113	2.7
lfate	14-1500	0.79	250	112	49.1

Downgradient wells are Nos. 21, 35, and 36; upgradient well is No. 98.

U.S. EPA 1983a; 1983b

Total number of measurements at the selected upgradient and downgradient wells (Nos. 21, , 36, and 98).

Times exceeded, percent = 100 x (number of measurements greater than criteria/total number measurements).

Data not available.

Many factors indicate that the slag pile does not contribute substantially to groundwater contamination. The limited available data indicate that groundwater metals concentrations upgradient of the slag pile are generally higher than downgradient concentrations. As discussed previously, metals in the slag are not readily leached; the concentrations of a majority of metals in the leachate did not exceed drinking water criteria; it appears that the metals that may be leached from the slag pile are relatively immobile in the soil; the water table is located under at least 20 ft of alluvium; and the closest groundwater receptor is 1.8 mi away. All of these factors greatly reduce the potential for the slag pile to contribute to groundwater contamination and subsequent human health risk.

VI. CONCLUSIONS AND RECOMMENDATIONS

There are presently no documented existing public health impacts caused by the disposal of granulated slag at the Smelter Hill site.

Potential future impacts on receptors via groundwater, surface runoff, or airborne contaminants have been demonstrated to be highly unlikely.

Available data indicate that the slag pile poses a low potential public health risk. Therefore, no further investigations or remedial actions are recommended.

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APPENDIX A

APPENDIX A

SLAG PILE INVESTIGATION

DATA REPORT

Prepared by
TETRA TECH, INC.

Prepared for
ANACONDA MINERALS COMPANY

May, 1985

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FIGURES

TABLES

I. INTRODUCTION

The field investigation of the granulated slag pile at the Anaconda Smelter has been completed in accordance with the Remedial Planning/Field Investigation Work Plan (CH2M HILL 1984) and the field operations plan (FOP) for the granulated slag pile focused investigation (Tetra Tech 1984a). This report summarizes the findings of the field team, and presents the results of the field and analytical laboratory's sample analyses. Interpretation and discussion of the data will be included in the Remedial Investigation (RI) report. This data report will appear as an appendix to the RI report.

TASK BACKGROUND

The study of the granulated slag pile is Focused Investigation II, one of four Focused Investigations that address potentially hazardous materials at the smelter site. Each focused investigation proceeds independently through the Remedial Investigation, Endangerment Assessment (EA), and if necessary, the Feasibility Study (FS) process. This focused investigation begins in Stage I of the Remedial Investigations. Should important data gaps exist after execution of the Stage I studies, the investigation would then move into Stage II in order to fill the data gaps.

SITE INVESTIGATION OBJECTIVES

The primary purposes of the Remedial Investigation activities are to characterize contamination and physical/chemical environmental parameters in sufficient detail to facilitate the Stage I Endangerment Assessment. In order to meet the EA analytical requirements, certain information regarding the granulated slag pile must be obtained. The objectives of the Focused Investigation are:

- Describe the physical characteristics of slag and determine the ability of wind and surface runoff to move slag from the pile.

- Provide measurements of area, volume, and mass of the slag pile.

- Describe the chemical composition of slag.

- Evaluate whether trace elements are readily leached from slag, and identify which elements may be most mobile.

- Determine whether data collected in this task provide sufficient information to answer questions about levels of contamination and contaminant movement from the slag pile.

In order to meet these objectives, the Work Plan proposed four major subtasks: Literature and Data Review, Field Study, Laboratory Analyses, and Data Reduction and Analysis. The Literature and Data Review includes the review of meteorological records; and an evaluation of the chemical characteristics of slag, the potential for transport of pollutants away from the slag pile, and the migration of heavy metals in surface and groundwaters.

The elements of the Field Work have been defined in detail during Task 3 of the RI/FS: Field Operations Planning. A Field Operation Plan (Tetra Tech 1984a) was specifically developed for the granulated slag pile task. The FOP includes the specific objectives and procedures for the field work. Deviations from those procedures will be discussed in this report.

II. GENERAL INFORMATION AND BASIC DATA REQUIREMENTS

SITE RECONNAISSANCE

A reconnaissance of the granulated slag pile was conducted on November 18-19, 1984 (Warren Hansen and Carole Schmidt, Tetra Tech). At this time, the ten slag sampling stations (Figure 1) were surveyed and staked as outlined in the FOP for sampling activities conducted on November 28-29, 1984. Sampling stations were surveyed as follows:

- The reference "benchmark" was established at the summit of the slag pile located in the southwest corner.

- Station SPT-3 (center top) was located using the angle to the smelter stack and distance from the benchmark. Distance and angle were determined from the Anaconda contour map (1 in = 500 ft) compiled by Horizons, Inc. (November 8, 1984).

- The transit was set up at Station SPT-3. Stations SPT-1, SPT-2, SPT-4, and SPT-5 were set to divide the top of the slag pile into four sections (see Figure 1). Angles relative to the stack and distance from Station SPT-3 were used to survey these stations.

- Stakes S_1, S_2, S_3, S_4, S_5, and S_6 were set along alignments to aid in surveying the side slope station locations (see Figure 1).

- Stations SPS-1, SPS-2, SPS-3, SPS-4, and SPS-5 were located by sighting along the alignments to the rim of the slag pile. Slope stations were located half way down the slope from the rim.
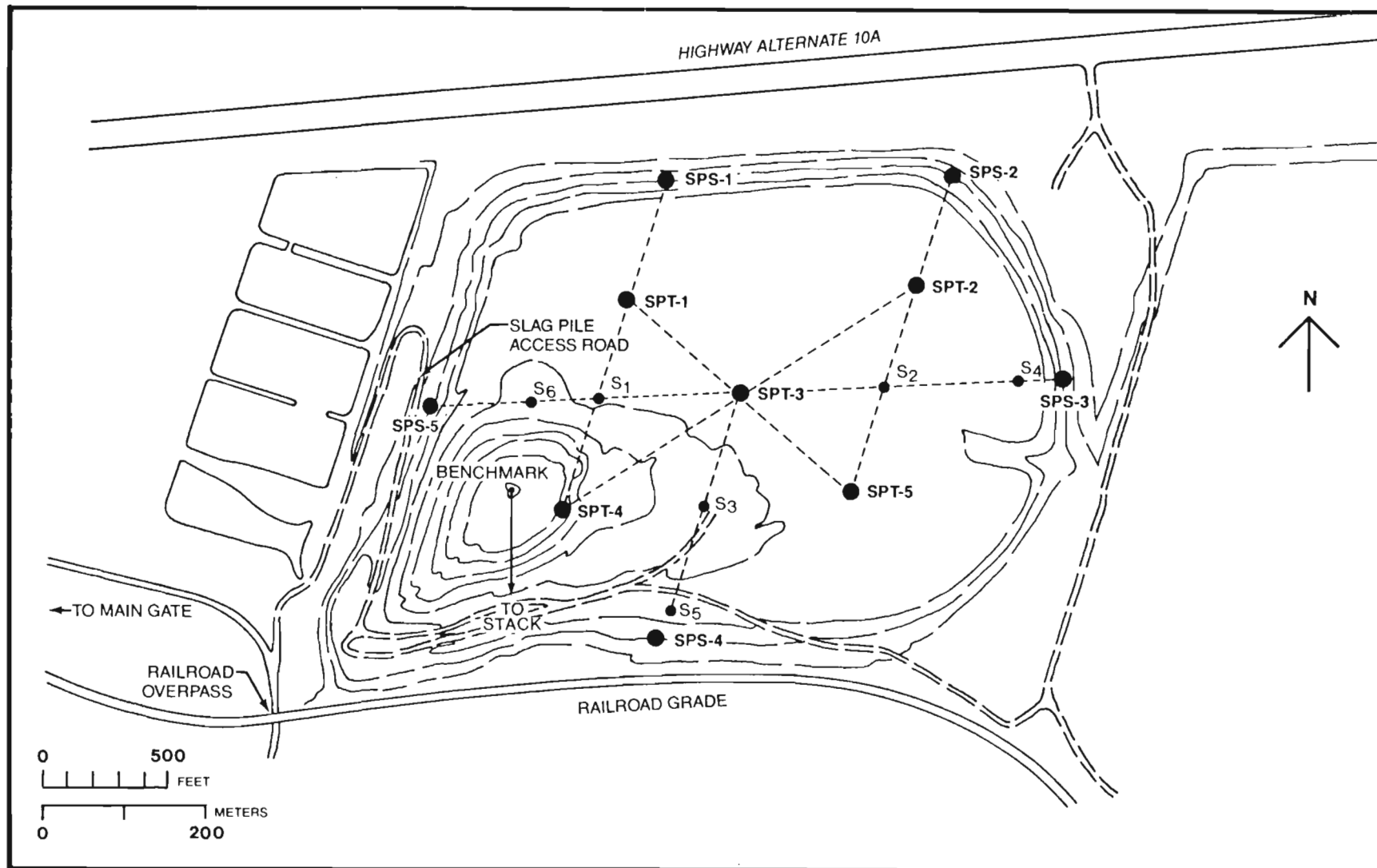
Figure 1. Locations of granulated slag pile sampling stations.

There was no evidence of surface drainage systems (channels, gullies, etc.) or of erosion or slag redistribution in the vicinity of the slag pile. The areal extent of the slag pile is accurate as depicted on the Anaconda Smelter Site map compiled by Horizons, Inc. from aerial photographs taken on November 8, 1984. The area and volume of the pile were calculated using contour and distance information scaled from this map. The calculated volume of the slag pile is 16 million yd^3 covering approximately 130 acres. The mass of the pile was calculated (assuming an average density of 1.96 g/cm^3) to be 26.5 million tons.

FIELD OBSERVATIONS DURING SAMPLING

As outlined in the FOP, slag sampling was conducted on November 28 and 29, 1984. The only deviation from the sampling procedures described in the FOP was the use of a 1.5-in diameter by 2.5-in long steel pipe to collect samples for in-situ density determination. The wooden box core originally prepared for this task was not strong enough to penetrate the slag.

General observations made during sample collection included the presence of vertical stratification with respect to slag hardness (aggregation), coarseness, color, and homogeneity. Stations sampled on the top of the slag pile showed signs of slag aggregation (crust) in the first 3- to 18-in depth depending on the location. This crust was easily penetrated with a shovel. Below the crust, the slag was very granular, firm, homogeneous in texture, and easily removed with the plastic scoops. This lower layer was from 6 to 21 inches thick (only 24 inches of slag were sampled) depending on location. Vertical slag stratification at the side slope stations included a very hard crust from 1 to 12 inches thick depending on location followed by a lower layer from 12 to 23 inches thick (only 24 inches of slag were sampled). This lower layer was very granular, firm, homogeneous in texture, and easily removed with the plastic scoops. A pick was necessary to break the hard surface crust at the side slope stations. Caving of the sampling hole was not a problem at any station. No variation in color with depth or station was noted. All slag samples were very black in color with a metallic sheen.

During sampling, the wind blew constantly with occasional gusts that would lift the slag a few feet in the air for a short distance. Loose slag was also blown along the surface crust of the pile. However, substantial wind blown transport of slag away from the pile was not observed.

III. TECHNICAL EVALUATION

LEACHATE COLUMN PREPARATION AND OPERATION

The slag leachate column tests were conducted in Tetra Tech's field laboratory in Butte. Prior to running these tests, the in situ slag density was determined and using this information, the pore volume of the leachate column was calculated. The calculated slag densities and sampling methods are summarized in Table 1. The average slag density was calculated to be 1.96 g/cm^3. Assuming this density, the pore volume ratio was calculated to be 0.168 cm^3 of acetic acid leaching solution for every gram of slag as described in Tt SOP-003. Therefore, the pore volume for the entire leachate column was calculated to be 3,076 ml.

The leachate column was assembled and operated as described in Tt SOP-003 (see Figure 2). To simulate the calculated in situ density of 1.96 g/cm^3, approximately 18,314 g of slag would have to be packed into the column. However, only 17,008 g could be packed into the first column and only 17,668 g could be packed into the second column.

During operation of the leachate column, the following observations were made:

- No short circuiting of leaching solution along the sides of the column was noted during filling or operation.

- The constant head was kept at 17.5 inches (see Figure 2) for both column tests. The hydraulic gradient was therefore 0.73 (inches hydraulic head per inch of column).

- The flow rate through the first column varied from 10.6 ml/sec (twentieth pore volume) to 16.7 ml/sec (first pore volume) and leveled off at approximately 11 ml/sec. The

TABLE 1. CALCULATED IN SITU SLAG DENSITIES
(AT 2 FT DEPTH)

Station	Sampling Method[a]	Sample Mass(g)	Density (g/cm^3)
SPT-1	Pipe	143.99	1.99
SPT-2	Pipe	138.78	1.92
SPT-3	Box	1,861.8	1.40[b]
SPS-3	Pipe	130.50	1.80
SPS-5	Pipe	152.51	2.11

[a] Volume of the steel pipe was calculated to be 72.43 cm^3 and volume of the wood box was calculated to be 1,327.35 cm^3. The wood box was used for one sample only before it broke.

[b] This value is not used in subsequent analyses due to problems with this field method.
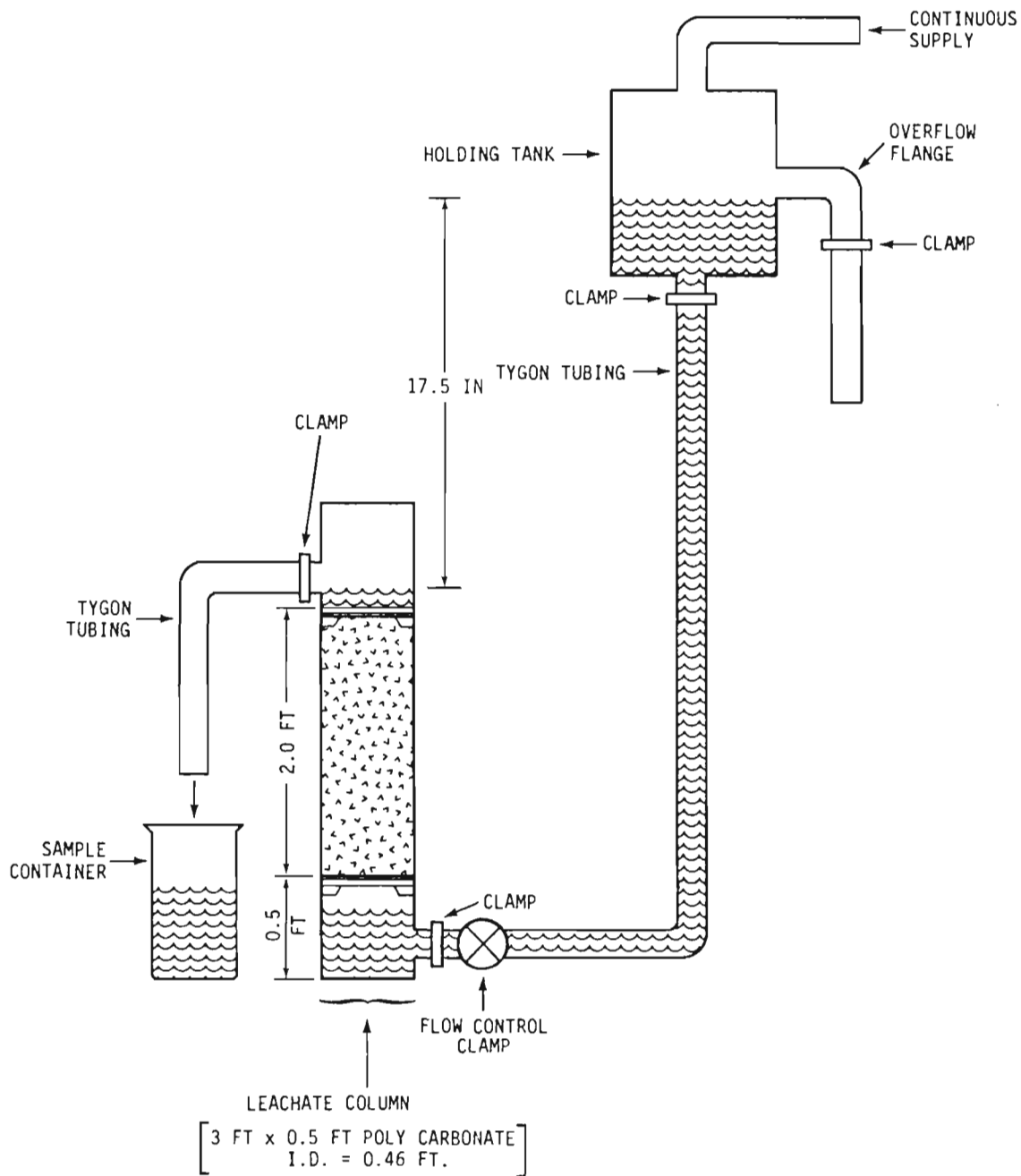
Figure 2. Constant head leachate testing column.

flow rate through the second column varied from 9.1 ml/sec
(first, second, fifth, and tenth pore volumes) to 10.0 ml/sec
(fifteenth, twentieth, and twenty-fifth pore volumes) and
leveled off at approximately 10 ml/sec.

● Total duration of flow through the column was calculated
   to be 2-h 12-min for first column and 2-h 19-min for the
   second column.

RESULTS OF SLAG LEACHATE ANALYSES

The results of the slag leachate analyses are summarized in Tables
2 and 3 for test columns 1 and 2, respectively.

Quality Assurance/Quality Control Results

Quality control checks for the analyses of the 14 leachate samples
consisted of the following additional analyses:

● Two acetic acid leaching solution blanks (listed in Tables
   2 and 3)

● One duplicate analysis of a leachate sample

● One spike analysis of a leachate sample

● One split with a "reference" laboratory for interlaboratory
   comparison.

Results from the duplicate and spike analyses are summarized in Table 4,
along with the method detection limits and the results from the laboratory's
most recent EPA (contract laboratory program) lab control analyses. Precision
results for lead were outside control limits. The replicates analyzed
were near the detection limit of the method, indicating analytical precision
is poor when results approach 3 ug/l. The arsenic result for the EPA lab
control standard was outside EPA control limits, however, this result was

TABLE 2. RESULTS OF SMELTER SLAG LEACHATE COLUMN TEST
COLUMN #1

				Pore Volume Number				
Parameter	1	2	5	10	15	20	25	Blank[a]
Metals, ug/l								
Antimony	<14	<14	<14	<14	<14	<14	<14	<14
Arsenic	3.8	<3.6	<3.6	<3.6	<3.6	<3.6	<3.6	<3.6
Cadmium	<4.0	18	25	19	18	16	<4.0	<4.0
Copper	128	633	5,450	10,800	10,900	11,000	9,460	722
Iron	<7.8	<7.8	<7.8	<7.8	<7.8	<7.8	11	34
Lead	<3.0	<3.0	7.2	10	13	19	25	5.6
Manganese	53	63	28	49	48	47	42	17
Selenium	<2.4	<2.4	<2.4	<2.4	<2.4	<2.4	<2.4	<2.4
Silver	<2.6	<2.6	<2.6	<2.6	<2.6	<2.6	<2.6	<2.6
Zinc	326	1,680	1,260	877	768	699	565	236
Sulfate, mg/l	30	3.5	<0.5	3.7	2.6	1.7	1.3	2.4
Conductance, umhos/cm	666	61	44	410[b]	69	55	50	51
pH	7.6	7.1	6.6	6.4	6.4	6.3	6.3	4.2
Alkalinity, mg/l $CaCO_3$	30	24	18	30	24	24	24	-

[a] Blank was prepared by rinsing tygon tubing and the column with the acetic acid leaching solution and preserving to a pH <2.

[b] Measured by California Analytical Laboratories (Masino, M. 26 February 1985, personal communication).

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TABLE 3.   RESULTS OF SMELTER SLAG LEACHATE COLUMN TEST
COLUMN #2

Parameter	Pore Volume Number							Blank[a]
	1	2	5	10	15	20	25	
Metals, ug/l								
Antimony	<14	<14	<14	<14	<14	<14	<14	<14
Arsenic	3.8	<3.6	3.9	4.7	<3.6	5.5	<3.6	<3.6
Cadmium	<4.0	30	28	18	18	<4.0	<4.0	<4.0
Copper	285	1,970	8,500	11,000	11,600	10,500	10,100	320
Iron	<7.8	<7.8	<7.8	<7.8	<7.8	12	34	21
Lead	3.2	3.4	7.5	9.2	11	16	21	3.7
Manganese	66	77	31	34	37	38	40	3.6
Selenium	<2.4	<2.4	<2.4	<2.4	<2.4	<2.4	<2.4	<2.4
Silver	<2.6	<2.6	<2.6	<2.6	<2.6	<2.6	<2.6	<2.6
Zinc	726	2,710	1,200	784	688	633	579	17
Sulfate, mg/l	33.4	4.5	<0.5	0.9	1.1	1.2	0.5	<0.5
Conductance, umhos/cm	311	67	52	57	57	52	49	31
pH	7.2	6.6	6.7	6.6	6.4	6.3	6.4	4.4
Alkalinity, mg/l $CaCO_3$	30	24	18	24	24	24	24	-

[a] Blank was prepared by taking a sample of the acetic acid leaching solution directly from the carboy and preserving to a pH <2.

TABLE 4. SUMMARY OF QUALITY CONTROL RESULTS FROM LEACHATE ANALYSES

Measurement	Method Detection Limit	RPD[a] (%)	Spike Recovery[b] (%)	EPA Lab Control Standard[c] 2/8/85
Metals, ug/l				
Antimony	14	NC[d]	103	Not evaluated
Arsenic	3.6	NC	81	223[e]
Cadmium	4.0	NC	106	94
Copper	2.0	1.4	94	111
Iron	7.8	9.2	102	99
Lead	3.0	21	119	97
Manganese	2.0	0.0	96	104
Selenium	2.4	NC	95	Not evaluated
Silver	2.6	NC	102	79
Zinc	4.0	4.7	99	96
Sulfate, mg/l	0.5	3.2	96	NA

[a] Relative Percent Difference (RPD) = [(Sample (S) - Duplicate (D))/((S+D)/2)] x 100.

[b] Spike Recovery = [(Spiked Sample Result - Sample Result)/Spike Added] x 100.

[c] Laboratory control standard analyzed as required by the EPA Contract Laboratory Program.

[d] NC = Non-calculable RPD due to undetected values.

[e] Analyzed by ICP.

obtained using ICP. Because the arsenic analyses on the leachates were performed using a graphite furnace method, this poor control standard result would not affect the leachate results.

Results from the interlaboratory comparison of one leachate sample are listed in Table 5. The relative percent difference (RPD) between arsenic results is high, but the results are near the detection limit. The results for cadmium and copper were initially significantly different between the two laboratories. Because the contract laboratory had performed well for these elements with respect to the duplicate and spike results reported, the results from the "reference" laboratory were checked for possible problems. Cadmium concentration from the "reference" lab was found to be 7 ug/l when reanalyzed, which brings the results within $\pm$ the detection limit of each other. Copper reanalysis resulted in a RPD of 5.4 percent.

Both of the leaching solution blanks seem to have relatively high concentrations of copper, iron, and lead compared to the concentrations of these metals in the first few leachate pore volumes. These results indicate possible contribution of these metals (contamination) to the slag leachate column by the leaching solution. The first blank (column No. 1) was prepared by rinsing the column and tubing with leaching solution and has higher concentrations of all measured metals than the second blank (column No. 2) which is a sample of the leaching solution taken directly from the storage carboy. This is probably caused by particulate contaminants (dust) associated with the column and tubing that were removed during rinsing. The second blank (column No. 2) is a more representative blank for both column tests because the leachate column and tubing were thoroughly rinsed with leaching solution and distilled water before and between each test. The fact that the concentrations of copper, iron, and lead in both blanks were higher than those measured in the first few leachate pore volumes indicates that these metals were initially retained by the slag in the column. As leaching time increased, the concentration of these metals in the leachate also increased.

TABLE 5. SUMMARY OF INTERLABORATORY COMPARISON OF LEACHATE ANALYSES

Measurement	Contract Laboratory[a] (A) Column #2 Pore Vol. 1	"Reference" Laboratory[b] (B) Column #2 Pore Vol. 1	RPD[c] (%)
Metals, ug/l			
Antimony	<14	<2	NC[d]
Arsenic	3.8	5	27
Cadmium	<4.0	7[e]	NC
Copper	285	270[e]	5.4
Iron	<7.8	<200[f]	NC
Lead	3.2	<2	NC
Manganese	66	NA[g]	NC
Selenium	<2.4	<2	NC
Silver	<2.6	<1	NC
Zinc	726	640	13
Sulfate, mg/l	33	38	17

[a] California Analytical Laboratory, West Sacramento, CA.

[b] Rocky Mountain Analytical Laboratory, Arvada, CO.

[c] Relative Percent Difference (RPD) = [(A-B)/((A+B)/2] x 100.

[d] NC = Non-calculable RPD due to undetected value(s).

[e] Results from reanalysis request. Initial reported values were 12 ug/l for Cd and 190 ug/l for Cu.

[f] High detection limit due to high concentration of iron in laboratory digestion blank.

[g] Not analyzed.

IV. SLAG PHYSICAL AND CHEMICAL ANALYSES RESULTS

The results of the physical and chemical analysis of the slag samples are summarized in Tables 6 and 7. Table 6 gives the results of the acid extractable metals and sulfur analyses while Table 7 lists the results of the sieve analysis for grain size determination.

Quality Assurance/Quality Control Results

Quality control checks for the analyses of the 10 slag samples consisted of the following additional analyses:

- One slag sample split in the field into 3 aliquots and submitted to the "contract" laboratory (California Analytical Laboratories, Inc.) as a blind triplicate

- One duplicate analysis by the "contract" laboratory

- One spike analysis by the "contract" laboratory

- One split with a "reference" laboratory (Rocky Mountain Analytical) for interlaboratory comparison.

Results from the blind triplicate analyses are summarized in Table 8. Results for all the elements are well within the control limit of 20 percent relative standard deviation or "coefficient of variation" specified in the Laboratory Analytical Protocol, indicating precision of the data is good. Initial triplicate results reported for sulfur were not within the control limits for precision. Reanalysis for sulfur was performed on all samples taking greater care to maintain consistent instrument operating conditions, resulting in better precision.

TABLE 6. RESULTS OF CHEMICAL ANALYSES OF SLAG SAMPLES

Parameter	SPT-1	SPT-2	SPT-3	SPT-4	SPT-5	SPS-1	SPS-2	SPS-3	SPS-4	SPS-5
Acid Extractable Metals (mg/kg dry weight basis)										
Aluminum	21,100	21,000	21,800	17,500	20,200	20,500	22,600	24,400	30,700	17,100
Chromium	354	115	436	297	342	217	323	205	45	278
Barium	1,170	1,340	463	1,690	1,450	3,190	980	266	485	766
Iron	300,000	316,000	334,000	341,000	288,000	325,000	320,000	377,000	188,000	326,000
Beryllium	<2.5	2.7	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5	<2.5
Cadmium	21	29	26	11	25	44	30	19	4.4	19
Cobalt	90	82	517	118	73	42	267	99	28	101
Copper	5,590	4,740	9,760	6,680	6,760	5,210	7,710	5,660	3,140	7,460
Lead	954	2,590	4,190	1,000	926	4,310	2,830	2,200	364	1,080
Nickel	40	22	291	54	23	<20	129	36	<20	73
Manganese	832	8,280	864	710	961	1,470	1,750	17,200	754	908
Mercury	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	0.08	<0.04
Zinc	38,800	25,800	36,300	21,200	34,700	23,400	29,900	23,800	8,380	23,700
Vanadium	118	229	213	93	190	192	184	127	83	132
Antimony	67	162	115	57	129	219	129	98	42	96
Arsenic	1,470	3,070	1,690	1,340	2,270	3,190	2,170	2,160	498	1,920
Molybdenum	57	82	670	67	57	3.2	485	14	<3	74
Selenium	<50	<50	<50	<50	<50	<50	<50	85	<50	<50
Silver	<5.0	7.8	5.8	5.8	5.4	9.5	6.1	88	17	9.0
Boron	17	170	27	15	22	9.7	22	<8.0	27	14
Tin	41	<20	220	99	126	67	118	129	<20	172
Total sulfur (% S, dry weight basis)	1.36	0.95	0.95	1.29	1.15	0.99	1.36	1.16	0.51	1.28
Pyritic sulfur (% S, dry weight basis)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
pH (1:1 slurry)	6.6	7.3-7.6	7.0	6.4	6.8	7.2	6.9	8.9	6.5	7.1

TABLE 7. RESULTS OF GRAIN SIZE ANALYSIS OF SLAG SAMPLES - PERCENT PASSING THROUGH SIEVE

| Station | 2 | 0.841 | Sieve Opening (mm)[a] | | | |
			0.420	0.250	0.105	0.074
SPT-1	96.9	62.3	15.5	6.4	1.5	0.9
SPT-2	90.7	36.8	12.4	6.0	1.4	0.8
SPT-3	100.0	76.5	17.4	6.7	1.4	0.8
SPT-4	98.1	65.2	19.0	6.6	1.4	0.9
SPT-5	98.3	67.6	20.2	9.0	2.2	1.4
SPS-1	96.2	50.5	7.8	2.1	0.4	0.3
SPS-2	99.7	91.2	48.3	25.9	5.0	2.3
SPS-3	98.0	59.2	14.4	5.2	1.0	0.5
SPS-4	61.0	18.5	6.0	2.6	0.7	0.5
SPS-5	96.0	39.1	9.0	4.2	1.2	0.8

[a] U.S. standard sieve mesh numbers are as follows: 2 mm-#10, 0.841 mm-#20, 0.420 mm-#40, 0.250 mm-#60, 0.105 mm-#140, and 0.074 mm-#200.

TABLE 8. SUMMARY OF BLIND TRIPLICATE ANALYSES OF SLAG SAMPLES

Measurement	SPT-3A	SPT-3B	SPT-3C	Mean	Standard Deviation	Coefficient of Variation
Metals, mg/kg (dry weight)						
Aluminum	21,800	21,200	20,800	21,267	503	2.4
Chromium	436	410	423	423	13	3.1
Barium	463	433	460	452	17	3.8
Iron	334,000	311,000	318,000	321,000	11,790	3.7
Beryllium	<2.5	<2.5	<2.5	<2.5	0	0
Cadmium	26	25	25	25	0.6	2.4
Cobalt	517	477	498	497	20	4.0
Copper	9,760	9,270	9,590	9,540	249	2.6
Lead	4,190	3,860	4,080	4,043	168	4.2
Nickel	291	277	287	285	7	2.5
Manganese	864	810	820	831	29	3.5
Zinc	36,300	34,200	35,000	35,167	1,060	3.0
Vanadium	213	203	202	206	6	2.9
Antimony	115	121	143	126	15	11.9
Arsenic	1,690	1,620	1,630	1,647	38	2.3
Molybdenum	670	636	644	650	18	2.8
Mercury	<0.04	<0.04	<0.04	<0.04	0	0
Selenium	<50	<50	<50	<50	0	0
Silver	5.8	<5.0	5.4	5.4	0.4	7.4
Boron	27	25	29	27	2.0	7.4
Tin	220	213	241	225	15	6.7
Total sulfur (% S, dry weight)	0.95	0.98	1.03	0.99	0.04	4.1
Pyritic sulfur (% S, dry weight)	<0.01	<0.01	<0.01	--	--	--

Results from the laboratory duplicate and spike analyses are summarized in Table 9 along with the method detection limits. The duplicate analyses for tin resulted in a RPD greater than 20 percent. However, the tin concentrations measured in solution were less than 5 times the EPA contract required detection limit, thus the control limit of 20 percent RPD does not apply at this low concentration. The spike recovery for mercury was low at 69 percent. The laboratory noted that low recovery for mercury was obtained due to the sample matrix, because matrix spikes on soil samples that were analyzed along with the slag samples resulted in good recovery.

Results from the interlaboratory comparison of the slag analyses are listed in Table 10. Good agreement (<10 percent RPD) was obtained for the majority of the elements. The RPD between laboratories is greater than 20 percent for antimony, cadmium, molybdenum, and tin. Antimony was reanalyzed by graphite furnace AA by the "reference" laboratory resulting in a much lower result of 5.8 mg/kg. To compare, the contract laboratory reanalyzed the sample by graphite furnace AA resulting in a much higher value of 239 mg/kg. (Both laboratories had obtained duplicate and spike results within the control limits.) Iron was added to the antimony calibration standards at approximately the same concentration as the sample digestates to determine if the high iron concentration is a possible interference, but no change in absorbance was noted. Both laboratories checked cadmium, molybdenum, and tin by ICP and obtained results comparable to the initial values. Investigation into the variability between the laboratories for these elements is continuing by requesting both laboratories to analyze the same digestates. No information was found indicating any EPA contract laboratory performance evaluations have been made for antimony, molybdenum, or tin in solid matrices. Therefore, expected comparability between the laboratories using the contract laboratory protocol for solid matrices cannot be stated for these elements at this time. Cadmium results for the EPA inorganic contract performance samples for the first quarter of 1985 indicate a coefficient of variation of 5 percent for cadmium for the laboratories reporting within the confidence interval established by EPA. Thus, better comparability between laboratories would be expected. However, considering the matrix and potentially nonhomogeneity of the split samples, the cadmium variability may be due to actual variability of cadmium concen-

TABLE 9. SUMMARY OF LABORATORY QUALITY CONTROL RESULTS
FROM SLAG ANALYSES

Measurement	Method Detection Limit (mg/kg, dry weight)	RPD[a] (%)	Spike Recovery[b] (%)
Metals			
Aluminum	100	2.2	93
Antimony	30	2.2	98
Arsenic	50	2.1	90
Barium	100	3	93
Beryllium	2.5	NC[c]	109
Cadmium	2.5	6	90
Chromium	5.0	1.0	98
Cobalt	25	1.7	92
Copper	25	3.6	98
Iron	25	2	96
Lead	20	1.6	94
Manganese	7.5	1.8	97
Mercury	0.04	NC	69
Nickel	20	5.3	90
Selenium	50	NC	99
Silver	5.0	NC	91
Boron	8.0	21	100
Molybdenum	10	0.0	96
Tin	20	33	96
Vanadium	25	2.1	95
Zinc	10	2.2	80
Total sulfur	100	1.7	99

[a] Relative Percent Difference (RPD) = [(Sample (S) - Duplicate (D))/((S+D)/2)] x 100.

[b] Spike Recovery = [(Spiked Sample Result - Sample Result)/ Spike Added] x 100.

[c] NC = Non-calculable RPD due to undetected values.

TABLE 10.   SUMMARY OF INTERLABORATORY COMPARISON OF SLAG ANALYSES

Measurement	"Contract" Laboratory[a] (A) SPT-1	"Reference" Laboratory[b] (B) SPT-1	RPD[c] (%)
Metals, mg/kg (dry weight)			
Aluminum	21,100	18,600	13
Antimony	67	85	24
Arsenic	1,470	1,600	8.5
Barium	1,170	1,040	12
Beryllium	<2.5	<0.8	NC[d]
Boron	17	<2.0	NC
Cadmium	21	47	76
Chromium	359	330	8.4
Cobalt	90	99	9.5
Copper	5,590	5,780	3.3
Iron	300,000	313,000	4.2
Lead	954	1,040	8.6
Manganese	832	910	9.0
Mercury	<0.04	<0.10	NC
Molybdenum	57	140	84
Nickel	40	44	9.5
Selenium	<50	<0.5	NC
Silver	<5.0	<3.0	NC
Tin	41	87	72
Vanadium	118	110	7.0
Zinc	34,800	37,400	7.2
Total sulfur (% S, dry weight)	1.36	1.13	18
Pyritic sulfur (% S, dry weight)	<0.01	0.06	NC

[a] California Analytical Laboratory, West Sacramento, CA.

[b] Rocky Mountain Analytical Laboratory, Arvada, CO.

[c] Relative Percent Difference (RPD) = [(A-B)/((A+B)/2] x 100.

[d] NC = Non-calculable RPD due to undetected value(s).

tration in the digestate. Because all other QC checks on the slag analyses were within acceptable limits and no background has been established at this time for expected laboratory comparability in this matrix, no data were rejected based on the interlaboratory comparison.

V. ANALYTICAL METHODS

SLAG LEACHATE ANALYSES

Specific conductance and pH were measured in the field laboratory by Tetra Tech personnel according to Tetra Tech SOP-010 and SOP-009 respectively (Tetra Tech 1984a). The conductivity for pore volume #10 from column #1 was questionably high, therefore California Analytical Laboratory was asked to reanalyze the remaining unacidified sample at their laboratory. Although still not consistent with other pore volumes, the result was a factor of 10 lower than the field laboratory result, thus the second analyses is included in the data table.

Alkalinity was measured by Anaconda Mineral Company's Butte water quality laboratory according to Standard Methods method 403 (American Public Health Association 1975).

Metals and sulfate analyses were performed by California Analytical Laboratory in West Sacramento according to the project's Laboratory Analytical Protocol (Tetra Tech 1984b). Antimony, cadmium, copper, iron, manganese, and zinc were determined using an inductively coupled plasma spectrophotometer (ICP). Arsenic, lead, and selenium were determined using graphite furnace atomic absorption spectroscopy. Sulfate was determined according to EPA Method 375.4 (U.S. EPA 1979).

SLAG PHYSICAL AND CHEMICAL ANALYSES

Slurry pH (1:1) was measured in the field laboratory by Tetra Tech personnel according to Tetra Tech SOP-011 (Tetra Tech 1984a). Metal analyses were performed by California Analytical Laboratories according to the project's Laboratory Analytical Protocol (Tetra Tech 1984b). All metal concentrations, except mercury, were measured by ICP after $HNO_3:H_2O_2$ digestion. Mercury was determined by cold vapor AA after an acid permanganate digestion.

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Northern Engineering and Testing in Billings, Montana, performed the sulfur analyses according to the ASTM procedures in the project's Laboratory Analytical Protocol. California Analytical Laboratories performed the grain size analysis by dry sieving as specified in the Laboratory Analytical Protocol.

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